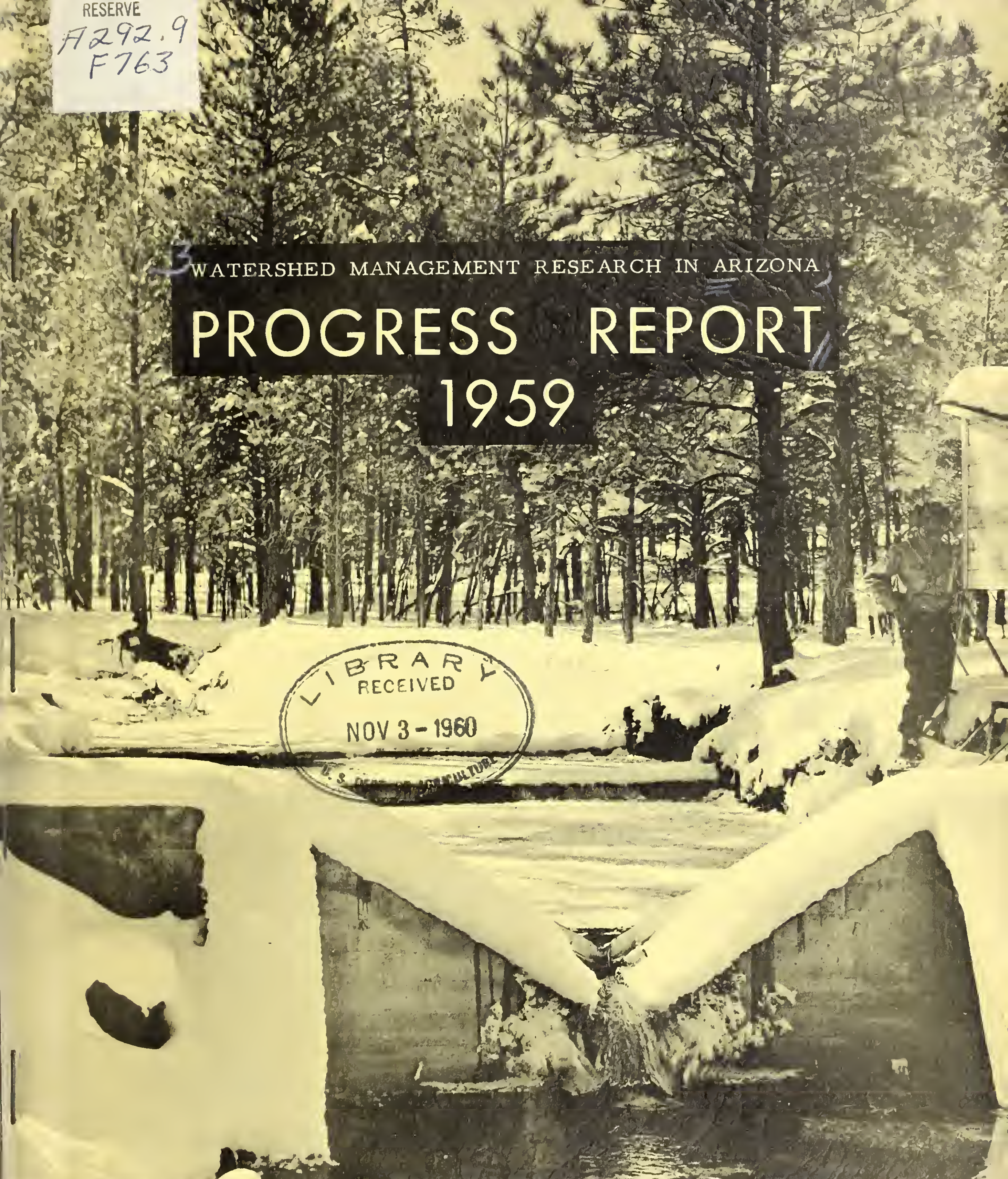

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Raymond Price, Director | Fort Collins, Colorado

FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

FOREWORD

Ordinarily we would wait until findings were more definite before publishing results of our research. However, interest in Arizona watersheds and their management is so great that we thought it would be helpful from time to time to make preliminary reports of our progress for the benefit of those interested and engaged in watershed management activities.

Included in this progress report are contributions by members of the Crops Research Division, U. S. Agricultural Research Service, reporting progress of cooperative research in chemical control of chaparral.

To help in a quick review of the report, we have highlighted each project on colored pages. I suggest you read these first then read the accompanying text for detail as needed.

Since this is a progress report we welcome any suggestions and comments that you may have.

Raymond Price

Director

WATERSHED MANAGEMENT RESEARCH IN ARIZONA

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CONTENTS

SCOPE OF CURRENT WATERSHED MANAGEMENT RESEARCH IN ARIZONA[1/]

by

Hudson G. Reynolds, Range Conservationist
Rocky Mountain Forest and Range Experiment Station[2/]

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Areas for recent intensive research have been established in five major vegetation types in Arizona. This grouping is desirable because of the great differences in environmental conditions and plant species among the various types.[3/] General characteristics of the vegetation types are shown in table 1 and their distribution is given in figure 1.

Table 1. --General characteristics of some major types of vegetation in Arizona (after Nichol, 1952)

Type of vegetation and main species	Proportion of State area	Elevation	Annual rainfall
	Percent	Feet	Inches
Mixed conifer (spruce, fir, aspen)	0.5	7,500 - 12,000	30 - 40
Ponderosa pine (ponderosa pine, Gambel oak)	7.5	6,000 - 7,500	20 - 30
Pinyon-juniper (pinyon pine, alligator juniper, Utah juniper)	17	5,000 - 7,000	12 - 20
Chaparral (shrub live oak and others)	8	4,000 - 5,500	12 - 20

1/ For a history of watershed management research in the Southwest see Price (1958). For an account of the overall watershed management research program of the Rocky Mountain Forest and Range Experiment Station in Arizona see Price and Hoover (1957).

2/ Central headquarters is maintained in cooperation with Colorado State University at Fort Collins; research reported here was conducted in cooperation with Arizona State University at Tempe and Arizona State College at Flagstaff.

3/ The main text of this report shows common names only. For a complete list of common and botanical names see page 79.

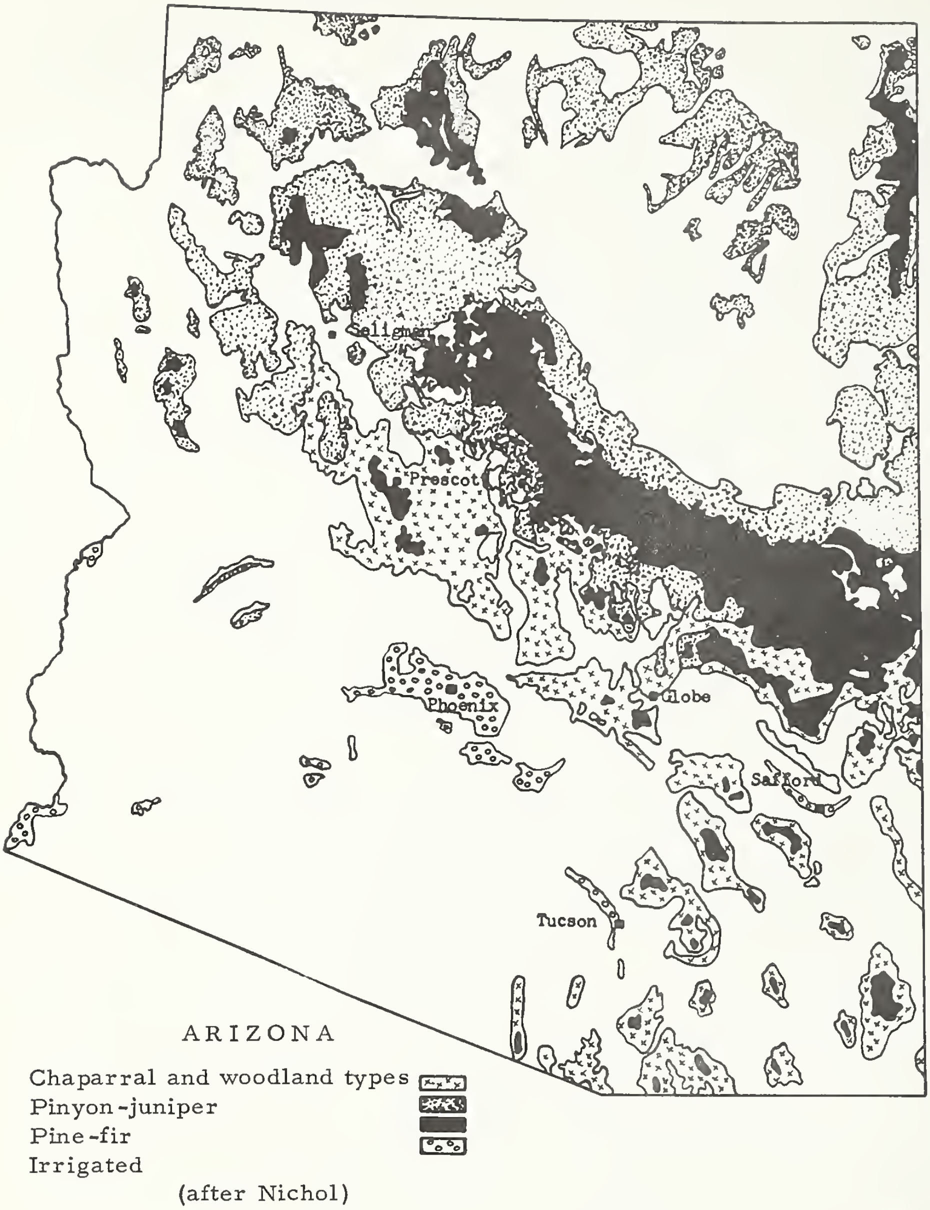
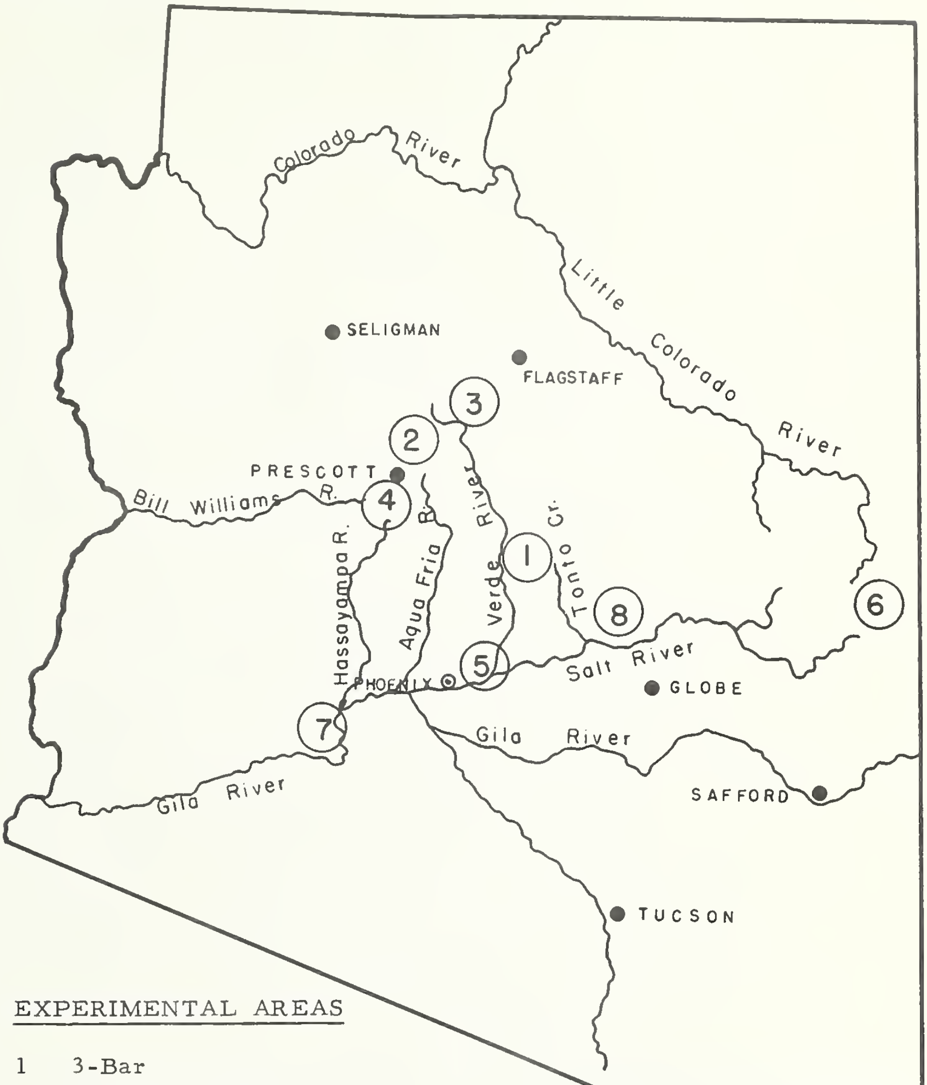


Figure 1.--Distribution of some major types of vegetation in Arizona. In general, the mixed conifer type occurs at the highest elevation along the Mogollon Rim, on San Francisco Mountain, and north of the Colorado River on the Kaibab Plateau. The ponderosa pine type, shown in black along with mixed conifer, occupies a broad belt along the Mogollon Plateau. The pinyon-juniper type lies at a slightly lower elevation and completely surrounds the ponderosa pine type. The chaparral type forms a band across the Mogollon front. Stream-bottom vegetation occurs at all elevations, though research activities at present are concentrated in tamarisk-seepwillow-arrowweed types along Salt River near Phoenix.

Detailed information on individual experimental areas is given in figure 2 and table 2.



EXPERIMENTAL AREAS

1 3-Bar
2 Mingus Mountain
3 Beaver Creek
4 White Spar
5 Granite Reef
6 Castle Creek, Willow Creek, Campbell-Blue
7 Arlington Refuge
8 Sierra Ancha Experimental Forest:
    Workman Creek
    Parker-Pocket Creeks
    Natural Drainages
    Base Rock
    Summit

Figure 2. --Location of experimental areas in Arizona where watershed management research is being conducted.

Table 2. --Location, characteristics, and general objectives of studies on experimental areas in Arizona where watershed management research is conducted

Area	Location	Vegetational type	Type of experimental area	General objectives
Willow Creek	Apache N. F.	Mixed conifer	Watersheds of 288 and 515 acres established in 1958	To determine effect of timber harvest and removal on water yields and sedimentation
Workman Creek	Sierra Ancha Expt. Forest	Mixed conifer	Watersheds of 248, 318, and 521 acres established in 1938	To determine effect of timber management and type conversion on water yield and sedimentation
Beaver Creek	Coconino N. F.	Ponderosa pine	8 watersheds from 200 to several thousand acres established in 1956-57	To determine the effect of timber management on water yield
Castle Creek and Campbell-Blue	Apache N. F.	Ponderosa pine	2 watersheds of 1,000 acres and 1 of 7,440 acres established in 1955	To determine the effect of commercial timber harvest on water yield and sedimentation
Parker and Pocket Creeks	Sierra Ancha Expt. Forest	Ponderosa pine-chaparral	Watersheds of 700 and 1,000 acres established in 1935-36	To determine water yield from steep, rugged watersheds of shallow soil
Beaver Creek	Coconino N. F.	Pinyon-juniper	3 watersheds in alligator juniper and 3 in Utah juniper established in 1956-57	To determine the effect of juniper removal on water yield and sedimentation
Natural Drainages	Sierra Ancha Expt. Forest	Chaparral	4 watersheds from 9 to 20 acres established in 1934	To determine the effect of grazing and chaparral conversion on water yields and sedimentation
Mingus Mountain and Whitespar	Prescott N. F.	Chaparral	2 watersheds on Little Copper Creek and 3 watersheds on Mingus Mountain established in 1958	To determine the effect of chemical treatment of chaparral upon water yield and sedimentation
3-Bar	3-Bar Wildlife study area	Chaparral	4 watersheds of 60 to 275 acres established in 1956	To determine the effect of wildfire and erosion control measures upon water, soil, and game
Base Rock	Sierra Ancha Expt. Forest	Chaparral-desert shrub	3 lysimeters 18 by 50 feet established in 1934	To determine the relation of kind and abundance of grass to surface and subsurface water flow and erosion rates
Summit	Sierra Ancha Expt. Forest	Chaparral-desert shrub	9 watersheds of about 1 acre each established in 1928	To determine the recovery of deteriorated ranges and comparative sediment rates from shrubs and perennial grass
Granite Reef	Tonto N. F.	Stream bottom		To determine establishment and spread of tamarisk, seepwillow, and other riparian species
Arlington Refuge	Arlington Wildlife Refuge	Stream bottom		To determine sprouting and reinvasion of tamarisk after mechanical removal

WATERSHED MANAGEMENT RESEARCH IN THE MIXED CONIFER TYPE

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HIGHLIGHTS

MIXED CONIFER

The mixed conifer type covers Arizona's high country at elevations ranging from 7,500 to 12,000 feet. It contains several species of spruce and fir as well as some quaking aspen--trees which thrive on the high precipitation (30 to 40 inches) and cool temperatures of this area.

Research is being done at Workman Creek north of Roosevelt Lake and in the White Mountains near Springerville. The objectives are to learn how plant cover influences streamflow and how the flow is affected by changes in cover. At Workman Creek there has been no detectable increase in streamflow following cutting of streamside hardwoods or following a 46-percent harvest of merchantable timber. A more drastic change of cover was accomplished in 1958 when 80 acres of moist-site timber was clear cut to convert that area to perennial grass. It is too early to evaluate this treatment.

Near Springerville, streamflow is being measured on four small watersheds, two in ponderosa pine (Castle Creek) and two in the mixed conifer type (Willow Creek). After the hydrologic behavior of these watersheds has been studied, the timber will be harvested from one in each pair to learn the effects on streamflow.

Snow-mapping studies were started in 1959 near Springerville to learn the importance of snow in various environments as a source of streamflow. The winter of 1958-59 turned out to be one of low snowfall and meager snowmelt runoff. Under these circumstances, peak discharges from snowmelt coincided with melting of snow on north and east aspects.

In preliminary comparisons of water yield from three small grassland watersheds and a nearby mixed conifer-grassland watershed, some runoff was measured from all except the small watershed of mixed conifer-grassland.

Soil-moisture investigations, also near Springerville, showed that soil moisture increased substantially during the winter months under grassland and aspen but decreased slightly under spruce, perhaps indicating higher winter water use by spruce.

WATERSHED MANAGEMENT RESEARCH
IN THE MIXED CONIFER TYPE

by

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Research was started in the mixed conifer type in 1938 on Workman Creek watersheds of Sierra Ancha Experimental Forest in central Arizona. Additional studies were initiated in 1955 and 1958 in eastern Arizona, near Springerville, on the Apache National Forest.

Figure 3. --Typical mixed-conifer cover in the headwaters of the Salt River. The scene is on a southeast slope of the East Fork of Willow Creek 33 miles south of Springerville, Arizona. The main trees shown are Douglas-fir, ponderosa pine, Engelmann spruce, and blue spruce.

Research goals in the mixed conifer type are: (1) to learn how kind and density of plant cover influence streamflow, (2) to develop methods for converting plant cover to the most efficient type for individual situations -- soil, aspect, and climate, and (3) to test the effects of management for timber and forage production upon water yield and quality.

THE WORKMAN CREEK STUDIES

Timber harvest and timber removal were started on Workman Creek in 1953 in cooperation with the Salt River Valley Water Users' Association. The period 1938 to 1953 was used to characterize water and sediment yields from the North, Middle, and South Forks of the 1,087-acre Workman Creek watershed (fig. 4).

Figure 4. --Workman Creek experimental watersheds. This picture was taken just after the cutting of all trees on 80 acres of North Fork. The openings in Middle and South Forks are meadows.

General Characteristics

Ponderosa pine dominates most of Workman Creek except the moist sites where Douglas-fir and white fir are most abundant. Gambel oak is an important secondary species, and minor species include New-Mexican locust, bigtooth maple, Arizona alder, and aspen. Some characteristics of the watersheds are tabulated below:

	Area (acres)	Average annual precipitation 1935-53 (inches)	Volume of sawtimber (bd. ft./acre)	Average streamflow 1938-53 (inches)
North Fork	248	32	13,000	3.19
Middle Fork	521	32	15,000	3.38
South Fork	318	32	21,000	3.42

Objectives

The major objectives of research here are to determine (1) streamflow and sediment yields of the natural forest, and (2) how streamflow and sediment are changed by good timber management practices on one watershed and by the replacement of moist-site trees with perennial grasses on another watershed.

Middle Fork serves as a climatic control. Treatments on North Fork are designed for maximum effect on water yields. South Fork is managed for high-quality pine timber.

Treatments and Results

North Fork

All Arizona alder and bigtooth maple adjacent to springs, seeps, and streams were cut during August 1953. Stumps were poisoned with ammate to prevent sprouting. A total of 153 alders varying from 1 to 33 inches in diameter and 946 maples varying from 1 to 11 inches were cut. Total basal area of these trees, 271 square feet, was approximately 0.6 percent of the basal area on the 248-acre watershed.

The 5 years (1954-58) following treatment showed no significant increase in annual or summer water yields in comparison with the control watershed.

During September and October 1958, 80 acres of moist-site vegetation adjacent to the stream channel, mostly white fir and Douglas-fir, were cleared from North Fork.

Large trees were cut with power saws and smaller trees were pushed over with bulldozers. Slash less than 12 inches in diameter and 10 feet long was piled in windrows suitable for burning and larger material was dragged off the watershed. Most of the forest litter and debris was also pushed into slash piles. This operation left an ideal seedbed for grass.

Area between slash piles was seeded immediately to a mixture of 40 percent slender wheatgrass, 40 percent Kentucky bluegrass, and 20 percent orchardgrass at the rate of 6-2/3 pounds per acre. An oak log was dragged crosswise over the area to cover seed; then an additional 3-1/3 pounds of the mixture was sown. Redtop was seeded along stream channels and seeps at the rate of 10 pounds per acre.

Slash was burned in March 1959; however, material larger than 4 inches in diameter was not completely consumed. Suppression of hardwood sprouts, removal of conifer reproduction, and additional seeding are anticipated to insure an adequate stand of grass.

Several years will be necessary before definite conclusions can be drawn as to the effect of changing one-third of a watershed from moist-site forest to perennial grass.

South Fork

The first management cut on South Fork began in June 1953, and was completed in November 1955. Gross volume removed was 3 million board feet. About one-third of the harvested timber had rot or other defect, and the sound volume was about 2 million board feet.

In terms of merchantable timber, the cut amounted to 46 percent; in terms of basal area the cut was 24 percent. Logging damage, access roads, and skid trails reduced basal area by an additional 6 percent. Improvement measures reduced the basal area by another 6 percent. Improvement consisted of poisoning undesirable trees and shrubs, isolating small areas of pine infested with mistletoe, and releasing young pine trees. Thus, total basal area reduction by logging, road building, and improvement measures was 36 percent.

Slash was piled and burned along main access roads. Logging roads, skid trails, and landing areas were seeded to perennial grass.

No significant change in water yields has yet resulted from the management cut, although more years of record will be necessary to establish conclusively the influences of this type of timber harvest.

Figure 5. --Effective seeding of a burn on the South Fork of Workman Creek. This 60-acre area was burned by wildfire on July 6, 1957. Prior to this time disturbance of the watershed from felling, skidding, and yarding had no measurable effect upon sediment at the gaging station, even though some sediment moved into stream channels from roads and other disturbed areas. After the wildfire, considerable soil movement followed the first summer rains. The most intense storm on record occurred on July 16, 1957. Rainfall totaled 3.41 inches in 3 hours, with 2.20 inches falling in a 30-minute period. After the summer rains, which totaled 10.62 inches, soil loss averaged 0.016 foot from 1,600 profile points, or nearly 1 acre-foot of sediment. The burned area was seeded to grass, and good establishment is protecting the area from further heavy erosion.

THE CASTLE CREEK WATERSHEDS

There are two Castle Creek watersheds each about 1,000 acres in area. They are located in eastern Arizona near the town of Alpine. Streamflow measurements were started in 1955.

Castle Creek climatic conditions are much different from those at Workman Creek. Precipitation at Alpine averages 20.4 inches annually. June-September precipitation is 9.9 inches or nearly half of the annual total. This compares with about one-third summer moisture at Workman Creek. Elevation at Castle Creek is about 8,000 feet. Timber is almost exclusively ponderosa pine, predominately mature and overmature stems, averaging 11,000 board feet per acre gross.

Objectives

The objective of research is to determine how the Forest Service method of harvesting timber influences water and sediment. Questions considered in the design were: (1) do harvesting practices on national forests remove sufficient timber to change water yields? (2) do present logging methods, road building practices, and slash disposal increase erosion and sediment yields?

Calibration Measurements

Wide variations in streamflow seem to characterize Arizona watersheds. The first of 3 years of calibration was characterized by very little runoff, the second year by a large proportion of runoff from summer precipitation and the third year by runoff from snowmelt. Distribution of streamflow and precipitation by months is summarized in table 3.

Figure 6.--During the spring runoff of Castle Creek in 1958, the East Fork weir pond trapped nearly 44 cubic yards of sediment, mostly coarse sand. The peak flow was 43 cubic feet per second. The watershed is not dissected by side channels nor is there evidence of extensive erosion. This stream channel, like many others in the pine-fir area of Arizona, flows through flat meadows and wide-bottomed forest areas. Often these channels are paved with coarse sediments, which are gradually moved downstream by high water.

Table 3.--Precipitation and streamflow, Castle Creek watersheds

Month	1955-56 Precipitation	1955-56 Runoff East Fork	1955-56 Runoff West Fork	1956-57 Precipitation	1956-57 Runoff East Fork	1956-57 Runoff West Fork	1957-58 Precipitation	1957-58 East Fork	1957-58 West Fork
	Inches								
Oct.	1.15	0	0	1.24	0	0	4.06	0.096	0.026
Nov.	.56	0	0	0	0	0	1.49	.147	.080
Dec.	1.18	0	0	.34	0	0	.59	.010	.010
Jan.	1.76	0	0	4.13	.005	.001	.92	.001	.006
Feb.	2.19	0	0	1.36	.037	.005	3.48	.244	.232
Mar.	0	.058	.018	2.13	.056	.021	5.89	1.657	1.956
Apr.	.82	.005	.007	1.51	.012	.012	2.47	5.565	3.532
May	.69	0	.004	2.14	.039	.016	.57	.149	.041
June	1.31	0	0	1.89	0	.002	1.83	.002	.001
July	2.53	0	0	5.61	.161	.187	2.04	0	0
Aug.	2.03	0	0	9.51	1.169	1.166	5.27	.004	.001
Sept.	.28	0	0	.35	.361	.101	6.47	.102	.050
Total	14.50	0.063	0.029	30.21	1.840	1.511	35.08	7.977	5.935

WILLOW CREEK WATERSHEDS

Willow Creek lies a few miles west of Castle Creek at a slightly higher elevation. Stream gaging stations were built in 1958 on two watersheds of 570 and 343 acres to obtain information on runoff from the upper part of the mixed-conifer type in eastern Arizona. When a relationship is established between runoff characteristics of the two watersheds, the timber will be harvested from one so that changes in runoff can be studied.

Snow studies are also being conducted on Willow Creek to learn how snow accumulates and melts on the watershed and the contribution of snow to streamflow.

Willow Creek is higher than Castle Creek and has different forest types. It contains a mixture of coniferous species on cool, north-facing slopes, including Engelmann and blue spruces, ponderosa pine, Douglas-fir, and white and subalpine fir. South-facing slopes are mostly covered with ponderosa pine.

SNOW STUDIES

To help decide the course of snow research in Arizona, the station set up a preliminary study in 1958 to learn the importance of snow as a source of streamflow. If melting snow is found to make a substantial contribution to streamflow, an intensive program of research is justified.

The preliminary studies are designed to provide information on snow accumulation and melt on different aspects, elevations, and vegetation types and to relate these factors to streamflow. Of particular interest is the

amount of runoff that comes from different environments during snowmelt, also the time at which runoff occurs.

The primary means of carrying out this research has been mapping areal snow cover at intervals and correlating it with streamflow. Mapping was done on Willow Creek and in the vicinity of Greens Peak. Both areas are on the Apache National Forest, in the headwaters of the Salt River.

During the spring of 1959, snow depth was below average for surrounding snow courses and spring runoff peaks were almost nonexistent on major streams in Arizona. In general, runoff peaked between the 7th and 11th of April (fig. 7).

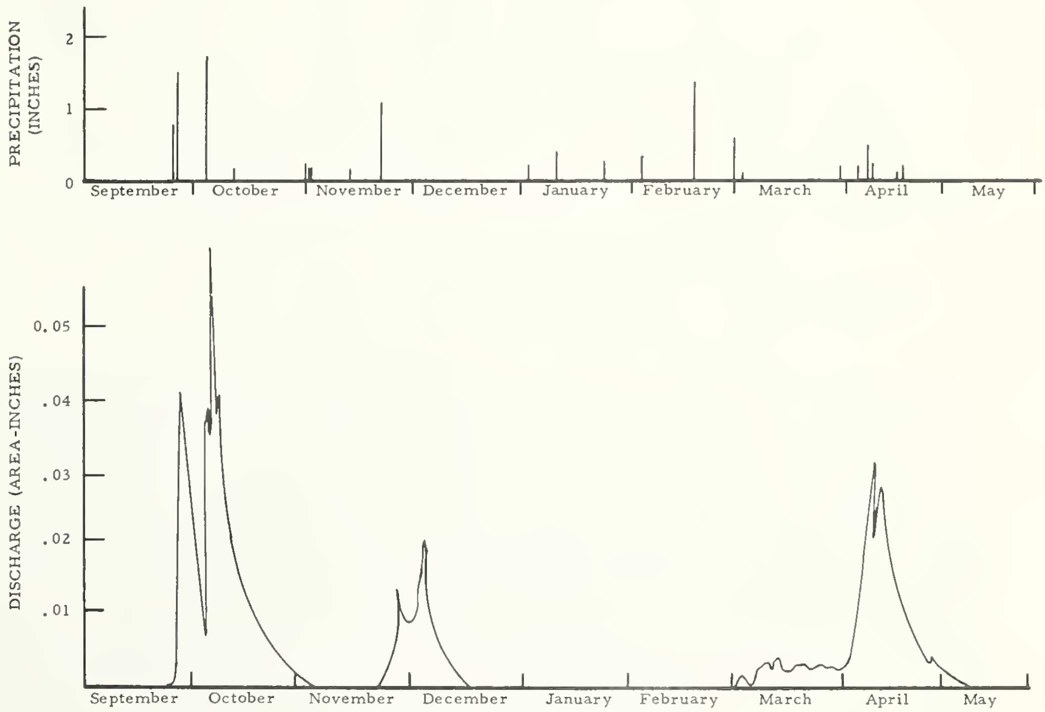

Figure 7.--Comparisons of peak discharges with periods of precipitation, for the East Fork of the Willow Creek watersheds in 1958-59. The peak in September and October corresponds with rainfall during the same months. The flow of November and December resulted from the large storm in November. Snow, which accumulated in January and February, melted during April.

Table 4 shows the relative order of disappearance of snow by aspect on Willow Creek. In general, snow melted first on south and east aspects. Last disappearance was on north and northwest aspects. Peak discharge coincided with melt from cool slopes -- north, east, and west. Snow from south slopes was essentially gone before peak discharges.

Table 5 shows that from April 3-11, both maximum and minimum temperatures increased slightly; snowmelt was rapid on north slopes, and coincided with peak discharge.

Records from the Greens Peak observation point are summarized in table 6.

Table 4. --Percent snow cover on East Fork Willow Creek watershed during snowmelt, March 20 to April 22, 1959

Slope and location	Date of mapping: Mar. 20	Apr. 1	Apr. 15	Apr. 22
	Percent of area covered with snow			
Northwest slope above weir	100	90	60	0
Northwest slope near weir	100	100	60	30
Northwest slope middle of watershed	90	45	3	0
North slope	95	80	25	3
Southwest slope near weir	20	0	0	0
East slopes near weir	30	30	7	0
East slopes middle of watershed	50	40	7	0
East slopes upper part of watershed	50	30	7	0
North slopes near stream channel	50	30	10	5
South slopes	10	0	0	0
	Degrees F.			
Temperature for week preceding:				
Mean maximum	52	52	55	55
Mean minimum	20	25	24	27

Table 5. --Snow cover, depth of snow, and water content compared with temperatures for a meadow near the middle of the East Fork of Willow Creek watershed, 1959

Date of mapping	Temperature for week preceding: Mean maximum	Mean minimum	Extent of snow cover: South slope	North slope	Meadow	Snow in meadow: Depth of snow	Average water content
	Degrees F.		Percent			Inches	
Mar. 13	53	17	5	100	100	18	5.5
Mar. 20	52	20	2	100	90	11	5
Mar. 27	48	20	0	100	80	7	3
Apr. 3	59	29	0	75	0	0	0
Apr. 11	59	28	0	30	0	0	0
Apr. 17	55	26	0	15	0	0	0
Apr. 24	57	26	0	3	0	0	0

Table 6.--Percent of snow cover by types as mapped from Greens Peak

Type and aspect	Date of mapping				
	Mar. 12	Mar. 19	Mar. 31	Apr. 14	Apr. 22
	Percent of snow cover				
Flat grassland	90	65	10	5	0
Conifer timber:					
North-facing	100	100	100	85	75
South-facing	75	50	40	0	0
Aspen:					
North-facing	100	100	80	80	0
South-facing	75	75	25	25	0
	Degrees F.				
Temperature for week preceding:					
Mean maximum	51	53	51	54	55
Mean minimum	14	19	23	24	27

Figure 8.--Snow cover from Greens Peak on March 19, 1959. On the Salt River, below this headwaters region, high daily peak for the spring (350 second feet) was on April 11, 1959. The peak seemed to be related to the start of snow disappearance from north-facing conifer timber areas and general disappearance of snow from other timber areas.

WATER YIELDS

Crest gages to compare yields of water from grassland and adjoining timber areas were installed at culvert openings on three small grassland and one mixed conifer-grassland watershed near Springerville. Four additional crest gages were installed on larger watersheds. Some runoff was measured from all except the small watershed of mixed conifer-grassland.

Runoff from the small grassland watersheds was probably the result of uniformly rapid snowmelt while the soil was frozen. The lack of surface runoff from the mixed conifer-grassland watershed can possibly be attributed to delayed snowmelt in the timber and subsequent absorption of water by areas of frost-free soil.

A crest gage was installed on the 3,500-acre grassland Seven Springs Wash March 11, 1959, when the stream was flowing about 2.5 second-feet. Between March 11 and March 20 a single rise of about 3.5 second-feet was recorded.

A crest gage on the 4,300-acre mixed conifer-grassland Black River watershed indicated a spring peak of about 22 second-feet between March 12 and March 20. By April 22 the stream was dry.

The measurements show that there is surface runoff from grassland watersheds in years of low winter precipitation but peaks are small.

SOIL MOISTURE

An exploratory comparison of soil moisture was begun in October 1958 to determine moisture used by grassland, aspen, and mixed conifers during the growing season. Gravimetric samples have been obtained for three sampling periods (October 1958, April 1959, May 1959) to depths of 8 feet.

Soil moisture was relatively high in October as a result of late summer rains. Winter precipitation was below normal, but soil moisture was still high in May, with some accretion under grassland and aspen:

	Grassland	Aspen	Spruce
	(Percent by weight)		
October 6-10, 1958	31.0	26.1	36.3
April 16-22, 1959	40.0	40.4	34.4
May 26-31, 1959	40.6	41.4	34.5

Additional measurements are planned. Access tubes for measuring soil moisture by the neutron method were installed in these plots during the last week in May, and first measurements were taken June 19, 1959. This method will be used for subsequent measurements.

WATERSHED MANAGEMENT RESEARCH IN THE PONDEROSA PINE TYPE

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HIGHLIGHTS

Ponderosa pine grows below the mixed-conifer type at elevations between 6,000 and 7,500 feet. Much of the type is of major commercial importance and forest products have been harvested from it for many years. However, little is known about streamflow and other hydrologic characteristics of the type or how they are affected by timber harvest.

Research to fill these gaps in our knowledge was started in 1956, with initial emphasis on basic hydrologic studies of rainfall interception and streamflow. The work so far has been centered on Beaver Creek.

PONDEROSA PIN

Pole-sized ponderosa pine canopies intercepted 11 to 25 percent of summer rainfall, depending on stand density. Density, in terms of basal area, varied from 48 to 278 square feet per acre. Evaporation from litter and humus on the forest floor was 7 to 25 percent of summer rainfall. Weight of the forest floor was 4 to 21 tons per acre, varying with age of the stand.

Streamflow is being measured on several pine-covered tributaries of Beaver Creek as part of the Beaver Creek Pilot Project. Flow has been limited mostly to the winter and early spring periods, with peaks coming at the time of snowmelt. Suspended sediment concentrations have been less than 500 parts per million.

WATERSHED MANAGEMENT RESEARCH IN THE PONDEROSA PINE TYPE

by

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Ponderosa pine is found between elevations of 6,000 and 7,500 feet on and to the south of the Mogollon Plateau (fig. 9). The type occupies about 7.5 percent of the State. Ponderosa pine is the dominant tree and is highly valued for lumber and pulp. Beneath the pine is a woody understory consisting of Gambel oak, New-Mexican locust, and a number of smaller shrubs; and where sufficient light filters through the canopy, perennial grasses such as Arizona fescue, mountain muhly, and muttongrass may be abundant. The understory vegetation, as well as the vegetation in parks and openings, is used by livestock and game. Where there is running or impounded water, recreation use is high and increasing rapidly. Annual rainfall averages 20 to 30 inches.

Figure 9.--Ponderosa pine watershed on the Beaver Creek Pilot Project, Coconino National Forest.

Watershed management research in the ponderosa pine type was started in 1956, with headquarters at Flagstaff. Objectives of research include: (1) a determination of such climatic and hydrologic characteristics as precipitation, rainfall interception, streamflow, and evapo-transpiration; and (2) an evaluation of the effects of timber and range management upon water yields and erosion. A part of this objective is to assist National Forest Resource Management in the design, instrumentation, and evaluation of watershed pilot studies on Beaver Creek.

RAINFALL INTERCEPTION

Not all rain falling on the forest soaks into the ground or runs off the surface. Some of it is caught by the tree canopies or by litter and other materials on the forest floor. This portion of precipitation is called interception.

Before the report on interception studies in the pine and pinyon-juniper types is presented, a word of caution should be said about interpretation of interception values: Intercepted precipitation is not all "lost" to streamflow. Although some of the intercepted moisture evaporates and consequently does not reach the ground, a portion of it may be used by the plants in lieu of moisture that would otherwise be withdrawn from the soil. Also, removal of the forest canopy will not increase the amount of rainfall reaching the ground by the same amount as was intercepted by the canopy, because there will still be a certain amount of interception from the new vegetation that replaces the trees.

Canopy Interception

Rainfall interception during the summer of 1957 was measured on nine different plots of pole-sized ponderosa pine varying in basal area from 48 to 278 square feet per acre (fig. 10). Between 11 and 25 percent of the gross rainfall was intercepted (table 7). There was an overall relation between rainfall interception and density of stands as expressed by basal area. Sparse stands intercepted significantly less rainfall than dense stands.

Table 7.--Rainfall and interception data for the period July 6, 1957, to October 28, 1957, for nine plots of pole-sized ponderosa pine

Location of plots and basal area in sq. ft. per acre	Trees per acre	Storms 0.01 inch or more	Total gross rainfall	Through-fall	Stem-flow	Net rainfall	Inter-ception
	Number		------	------ Inches	------	------	Pct.
Fort Valley							
48	160	24	5.30	4.64	0.03	4.67	12
138	380	23	9.24	7.81	.25	8.06	13
266	720	21	6.46	4.73	.22	4.95	23
James Canyon							
61	190	26	7.26	6.38	.07	6.45	11
120	550	25	6.73	5.26	.22	5.48	19
278	1,590	25	7.08	5.48	.36	5.84	18
Beaver Creek							
90	310	30	8.50	7.38	.15	7.53	11
166	360	29	9.00	6.60	.13	6.73	25
256	840	33	9.49	6.78	.79	7.57	20

Figure 10. --Measuring rainfall under canopy of pole-sized ponderosa pine. The rain caught in the cans on the forest floor is called "through-fall." Bands around the trees in the center are troughs to catch rain flowing down the trunks (stemflow). In this stand through-fall was 71.4 percent of gross rainfall and stemflow was 8.3 percent. Thus 20.3 percent less rain reached the ground here than in a nearby opening.

Forest Floor

Weight and moisture content of the forest floor were measured to provide information on the role of the forest floor in interception and evaporation of rainfall (fig. 11). Weights also provide an index to the amount of protection the forest floor offers the soil, and moisture contents are an index to fire hazard.

Under pole-sized stands the weight of forest floor was more closely related to age of stand than to number of stems per acre or basal area. Measured weights ranged from 4 to 21 tons per acre, depending on age and density of the stand (table 8).

Table 8. --Forest floor (litter and humus) weight in pole-sized ponderosa pine stands 30 to 70 years old

Plot location	Density: Stems per acre	Density: Basal area per acre[1]	Height of dominant trees	Age	Ovendry weight of forest floor per acre
	No.	Sq. ft.	Feet	Years	Tons
89A	190	61	21	30	3.7
	550	120	38	47	10.9
	1,590	278	33	52	13.2
Fort Valley	160	48	24	32	4.9
	380	138	35	59	10.4
	720	266	47	63	17.4
Beaver Creek	310	90	30	48	5.8
	360	166	38	62	18.4
	840	256	57	70	21.1

[1] Measured at d.b.h.

Figure 11. --
Litter and humus were collected from 1-square-foot plots such as this. Weight and moisture content of the samples were then measured to find out how much interception and evaporation is taking place from the forest floor.

Moisture loss was related to gross precipitation and weight of forest floor. Between 0.2 and 1.1 inches of moisture were evaporated from the forest floor on nine plots of pole-sized ponderosa pine during August 1957 (table 9), a loss of 7 to 25 percent of gross precipitation.

Table 9. --Forest-floor moisture data for the period August 1-30, 1957

Plot location	Forest-floor weight	Total rainfall	Evaporation for period	Evaporation as percent of rainfall
	Tons/acre	Inches	Inches	Percent
89A	3.7	2.5	0.2	8
	10.9	3.7	.5	14
	13.2	3.9	.6	15
Fort	4.9	1.8	.2	11
Valley	10.4	3.9	.5	13
	17.4	2.4	.6	25
Beaver	5.8	4.2	.3	7
Creek	18.4	4.4	.8	18
	21.1	6.4	1.1	17

STREAMFLOW MEASUREMENTS

Streamflow is being measured on the tributaries of Beaver Creek as part of the study of hydrologic characteristics of the ponderosa pine and pinyon-juniper types. Flow is gaged by flumes of the type shown in figure 12. In 1957-58 flow occurred on ponderosa pine watershed No. 9 during October through April; in 1958-59 lower flow was observed during the February-April period. Thus far, highest streamflow has coincided with the period of rapid snowmelt. Peak flows have been high.

Sediment concentrations are not excessive during November-May flows originating from undisturbed pine watersheds. Less than 500 parts per million of suspended sediment were contained in 73 water samples taken weekly from five pine watersheds in 1957, 1958, and 1959.

Figure 12.--Flow measurements in a flume on Beaver Creek. The operator is using a velocity head rod to measure water depth and velocity. Flumes of this type are located on 14 small watersheds where various land treatments are underway or planned. To date the flumes have carried discharges up to an estimated 380 cubic feet per second. The flume will measure a wide range of flows and carry large debris loads. Rating of the flume is based on tests in the Colorado State University Hydraulics Laboratory and flow measurements in the field.

WATERSHED MANAGEMENT RESEARCH IN THE PINYON-JUNIPER TYPE

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HIGHLIGHTS

The pinyon-juniper type is at a slightly lower elevation than ponderosa pine; also it grows on a somewhat drier site where annual precipitation averages 12 to 20 inches. Water yields and sediment rates are largely unknown.

Current watershed management research, started in 1956, has been along the same lines as in the ponderosa pine type, being directed first toward characterizing the hydrology then toward learning the effect of cover changes.

The first hydrologic study involved rainfall interception. Average interception by Utah juniper canopies varied from 6 percent in stands with 17 percent average crown cover to 22 percent in stands with 59 percent average crown cover.

Surface runoff from small plots in light, medium, and dense stands of Utah juniper was 0.73, 0.42, and 0.17 inch, respectively, during a 1-year period. This corresponded to 0.22 inch from three nearby entire watersheds.

The only time the streams flowed on these three watersheds was after two September rainstorms. Rainfall amounts were greatly different during the two storms; however, equal amounts of runoff were produced (0.11 inch). This apparently was because soil moisture was low before the big storm and high before the small storm.

WATERSHED MANAGEMENT RESEARCH IN THE PINYON-JUNIPER TYPE

by

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At present, pinyon-juniper research is concentrated on Beaver Creek, and personnel are stationed at Flagstaff. General responsibilities are similar to those for the ponderosa pine project; namely, to provide basic information on hydrologic characteristics of the pinyon-juniper type and to assist National Forest Resource Management in the design, instrumentation, and evaluation of the watershed pilot studies on Beaver Creek. This report summarizes some of the findings from recent hydrologic studies of rainfall interception and surface runoff.

The pinyon-juniper type lies adjacent to and almost surrounds the ponderosa pine type at a slightly lower elevation. The most common tree species in the type are Utah juniper, alligator juniper, and pinyon pine. Tree stands vary in character from very dense to sparse. Open stands, where grazing has not been excessive, have a good understory of perennial grasses.

Water yield and sediment rates are largely unknown. Annual rainfall is 12 to 20 inches. Because of the low rainfall water yields are believed to be less than in the pine type. The large areas of bare soil and occasional flash floods indicate high erosion and sediment movement.

INTERCEPTION

Studies were started in 1958 to learn how much rainfall is intercepted by tree crowns in stands of different densities (see the report on interception in the section on ponderosa pine for an explanation of interception studies). Results are reported in table 10 and figure 13.

Table 10. --Interception in the Utah juniper type as related to stand density

Stand density class	Average crown cover	Trees per acre taller than 6 feet	Precipitation	Interception	Interception as percent of precipitation
	Percent	Number	Inches	Inches	Percent
Light	17	45	14.95	0.89	6.0
Medium	42	160	15.01	2.76	18.4
Dense	59	220	15.01	3.24	21.6

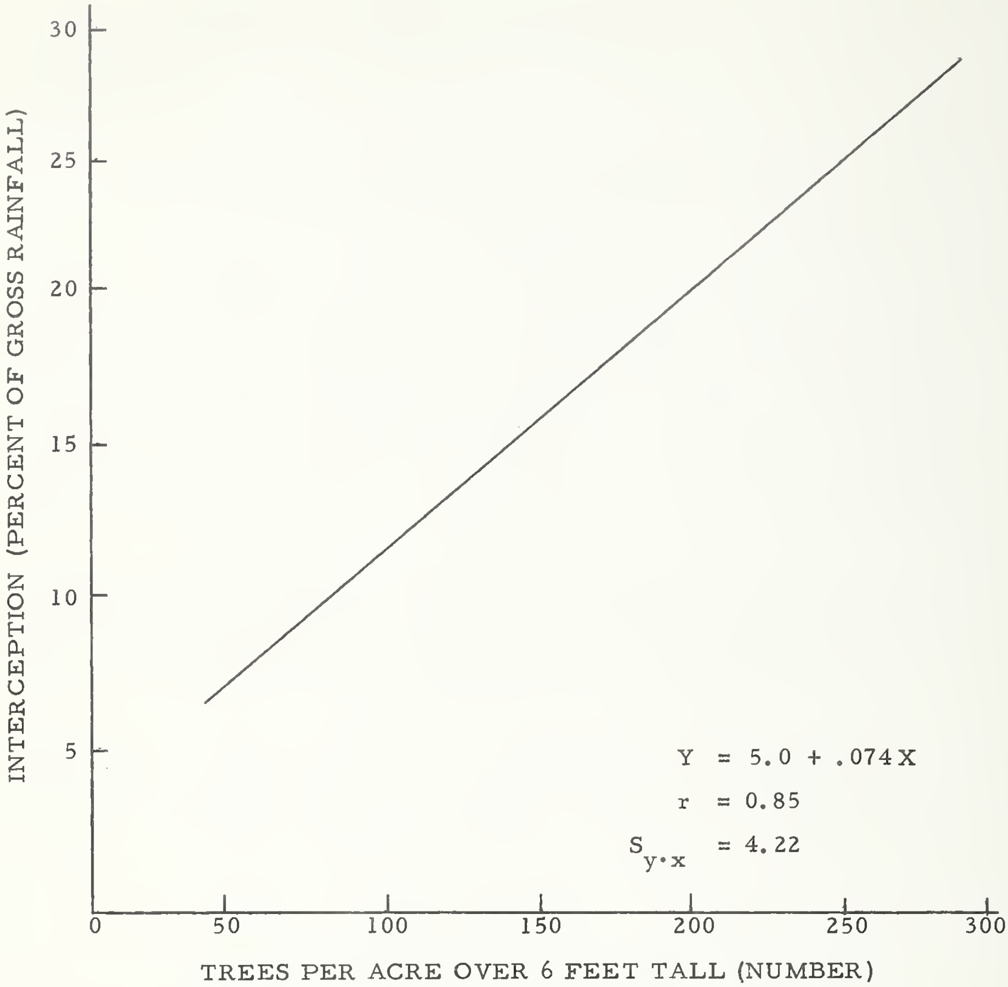

Figure 13.--Relation between density of Utah juniper and rainfall interception. Interception between April 1958 and April 1959 accounted for 1.8 to 24.1 percent of gross precipitation.

SURFACE RUNOFF

Twelve 2- by 3-foot plots were installed in light, medium, and dense stands of Utah juniper to provide an estimate of surface runoff (fig. 14). From April 1958 to April 1959, average runoff from the plots was 0.73, 0.42, and 0.17 inch, respectively, for the three densities of juniper. Soil depth was less in the more open stands and it is not correct to assume that tree density was the primary factor influencing runoff.

Surface runoff from entire watersheds amounted to 0.22 inch during this period. This was approximately one-half the amount measured on the medium density runoff plots. The watershed measurements came from three gaged Utah juniper watersheds in the vicinity of the small surface runoff plots.

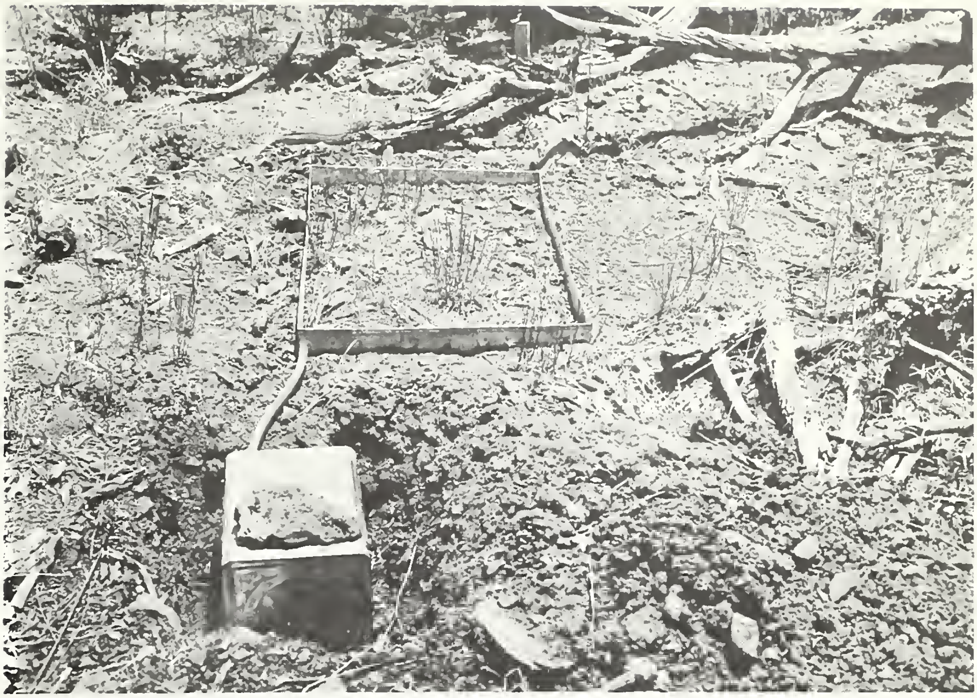

Figure 14.--A plot used for measuring surface runoff in the Utah juniper type. The 2- by 3-foot plot frame is hammered a few inches into the ground. Surface runoff flows into a trough at the lower end of the plot and is carried through a hose into the collection tank where it is weighed. Weight of water is converted to inches of surface runoff.

STREAMFLOW

Flumes on the experimental watersheds adjacent to the density plots are of the same type shown by figure 12. From April 1958 to April 1959, streamflow was recorded for a total of 45 hours at flume No. 3, 39 hours at flume No. 2, and 21 hours at flume No. 1. Equal flows of 0.11 inch occurred after two storms. The characteristics of the storms were:

Date of storm	Duration (Minutes)	Amount (Inches)	Maximum 10-minute intensity (Inches/hour)
September 12	900	3.50	4.50
September 29	30	.60	4.10

The fact that similar amounts of runoff came from two storms so different in size may be attributed to differences in soil-moisture conditions before the storms. Before the 3.50-inch storm, soils were near wilting point; however, by the time of the second storm they were wet, having received an additional 5 inches of rainfall.

WATERSHED MANAGEMENT RESEARCH IN THE CHAPARRAL TYPE

HIGHLIGHTS

Chaparral is the brushy vegetation that covers much of central and southeastern Arizona at elevations between 3, 500 and 6, 500 feet.

As in the higher elevation types, the first objective of research in chaparral has been to learn more about existing vegetation, climate, and streamflow before attempting changes. Observations thus far have produced some surprises, particularly in regard to amounts of rainfall and streamflow. Wildfire has brought about unplanned changes in some experiments.

Shrub live oak is the most common plant in the type, occupying half to three-quarters of most chaparral stands. It sprouts vigorously, especially after fire, and in one test was not killed even after being burned in 6 consecutive years. Shrub live oak canopy had the effect of reducing density of weeping lovegrass; grass density was one-third as great where the canopy was complete as in areas with no oak.

Chaparral lands are not always as dry as they appear to the casual summer visitor. Annual rainfall in excess of 30 inches has been measured, though more often it is between 16 and 25 inches. Considerable streamflow comes from some chaparral watersheds too. Streamflow on test watersheds has varied from 1 to 10 percent of the total precipitation. Except at the desert margin, most of the streamflow has come during the winter months.

A fire in 1959 changed the whole hydrologic picture at 3-Bar--heavy runoff has since been produced by both summer and winter storms. Sediment yields, which before the fire were very low, have in a half-year period amounted to as much as 40, 000 tons per square mile.

Chemical control of chaparral is being studied (see next two sections) as well as control by root plows and fire. First-year observations indicate that the root plow was highly effective in killing all species of shrubs, including shrub live oak. So far attempts at prescribed burning during low-hazard periods have not been successful.

WATERSHED MANAGEMENT RESEARCH IN THE CHAPARRAL TYPE

by

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CHARACTERISTICS OF CHAPARRAL

About 5-1/2 million acres of broken, intermediate-elevation, mountainous land in central and southeastern Arizona is occupied by chaparral shrubs and associated oak-woodland species. The brush stands lie at elevations of about 3,500 feet to more than 6,500 feet and receive from 14 to 25 or more inches of annual precipitation. Sixty percent of this precipitation comes during the October-through-May period. Although once grazed by sheep and goats, nearly all chaparral ranges are now stocked by cattle on a yearlong basis. Chaparral is also considered important range for deer. Water yield, where measured, has ranged from 0 to 2.35 inches per year. Over 80 percent of the annual water yield has occurred in winter. Pressing problems are high sedimentation rates, high consumptive use of water by a variety of woody shrubs, and the need for replacing plants of low forage value with more valuable plants.

Figure 15. --A typical chaparral stand in central Arizona.

Chaparral in Arizona is a natural, complex grouping of shrubby species with generally uniform appearance but variable composition. To date, 59 shrub species have been identified on study areas along with 66 forbs and 51 grasses. Shrub live oak is the most abundant plant on nearly all sites. Skunkbush sumac, desert ceanothus, and mountainmahogany are common. Silktassel, menodora, and cliffrose are less abundant, but because of their high palatability, are important. Two species of manzanita are found as dense thickets on some local sites.

Composition and crown cover on three unburned and two burned areas are shown in table 11. Shrub density varied from 21 to 70 percent on the unburned areas and from 5 to 36 percent on burned areas; grass density was less than 5 percent on both. Shrub live oak made up 43 to 73 percent of the total cover on unburned areas and 69 to 84 percent of the cover on burned areas.

Table 11. --Plant density and shrub composition on representative unburned and burned chaparral stands

Treatment, area, and year		Density		Shrub composition			
		Grass	Shrub	Shrub live oak	Mountain-mahogany	Skunkbush sumac	Others
		Percent					
Unburned							
3-Bar "D"	1958	1.5	70.2	43.0	9.8	2.6	44.6
Bender	1958	--	40.2	73.1	3.7	11.4	11.8
Skull Valley	1939	4.65	20.7	69.6	Trace	9.1	21.3
	1958	.72	22.6	67.3	1.4	9.7	21.6
Burned							
Mingus Mountain							
(burned 1956)	1956	.12	5.4	80.0	.5	11.4	8.1
	1957	.30	15.1	80.4	1.4	12.8	5.4
	1958	.35	27.2	69.4	2.1	14.8	13.7
Pinal Mountain							
(burned 1951)	1952	.72	21.3	84.0	0	0	16.0
	1956	1.28	35.7	82.0	0	1.4	16.6

TIMING OF GROWTH OF CHAPARRAL SPECIES

A study of chaparral phenology was begun at Whitespar and Mingus watersheds near Prescott in 1959 and will be extended to other sites during the coming year.

Other studies indicate that although the various species exhibit slightly different timing of growth, all have a major growth period during spring and may display a second flush of growth during late summer if July and August rains are adequate.

RESPONSE OF CHAPARRAL SPECIES TO FIRE

In 1953, a study to test the response of shrub live oak to repeat burning at intervals of 1, 2, 3, 4, and 5 years was laid out at Sierra Ancha. Some

plants were burned by blowtorch for the sixth time in June 1958. Sprouts present after burning, in proportion to the number of stems before the initial burn in 1953, were:

1953	1.0	1956	3.1	1958	0.3
1954	5.9	1957	1.3	1959	0.1
1955	2.7				

Many chaparral species are able to regenerate after a fire, but this ability varies with species. Regeneration of chaparral following fire has been studied in detail on areas burned and seeded at Pinal Mountain since 1951 and at Mingus Mountain since 1956. From observations made to date, the relative capacities of several important chaparral species for regeneration by sprouting and seeding are tentatively indicated in table 12.

Table 12.--Relative sprouting capacity of selected chaparral species

Species	Vigorous sprouter	Moderate sprouter	Non-sprouter	Reproduce by seed
Shrub live oak	x			
Sugar sumac		x		
Skunkbush sumac		x		
Pointleaf manzanita			x	x
Pringle manzanita			x	x
Desert ceanothus			x	x
Mountainmahogany		x		x
Wright silktassel		x		
Algerita	x			
Emory oak		x		

PRODUCTION OF HERBAGE ON BURNED CHAPARRAL

On Mingus Mountain burn additional measurements are being made of herbage production and utilization by livestock and deer. Measurements are taken twice a year on 100 transects located on the upper, middle, and lower parts of the 18,000-acre burn. Cover and production of brush, grass, and forbs are shown in figure 16.

CONTROLLED BURNING EXPERIMENTS

Study of fire as a means of eradicating or controlling chaparral started in May 1958 near Prescott. Safe, prescribed, control burning of chaparral appears impractical during the high-hazard period of late spring and early summer, so initially the main emphasis has been on development of methods for burning during the noncritical season. An evaluation is being made of ignition and rate of spread under different conditions of fuel compaction, fuel volume, changes in fuel moisture, and climate.

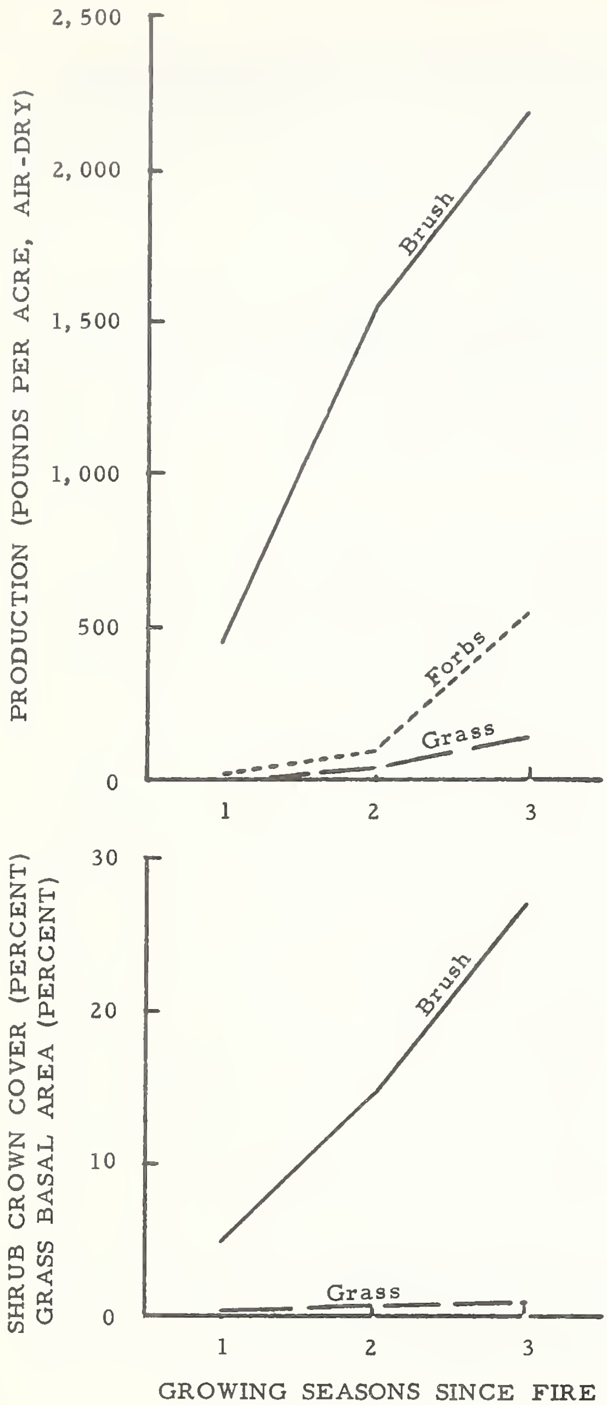


Figure 16. -- Cover and production of shrubs, grasses, and forbs following the 1956 wildfire at Mingus Mountain near Prescott, Arizona.

Two trial burns were conducted in October 1958 and April 1959 on chaparral that had been either partially or completely smashed to provide dry fuel. Average crown density of partially and completely smashed brush was 34 to 36 percent, respectively. Individual clumps ignited readily, but fire did not carry to adjacent clumps. Quantity of fuel averaged approximately 5 tons per acre and was inadequate to support a running fire under weather conditions existing at the time of burning. In contrast, considerably

less dense but much drier brush was burned over and completely consumed by wildfire on parts of the 3-Bar areas under the extreme high-hazard conditions during the latter part of June 1959.

EFFECTS OF SHRUB COMPETITION ON GRASS DENSITY AND PRODUCTION

Amount of shrub canopy seems to be inversely related to growth and production of desirable herbaceous plants. This relationship was found in shrub live oak chaparral near Skull Valley, where a detailed reconnaissance survey was conducted during 1939.

Relationships between crown cover of shrub live oak and basal area and production of artificially seeded weeping lovegrass for a burned area near Globe are shown in figure 17.

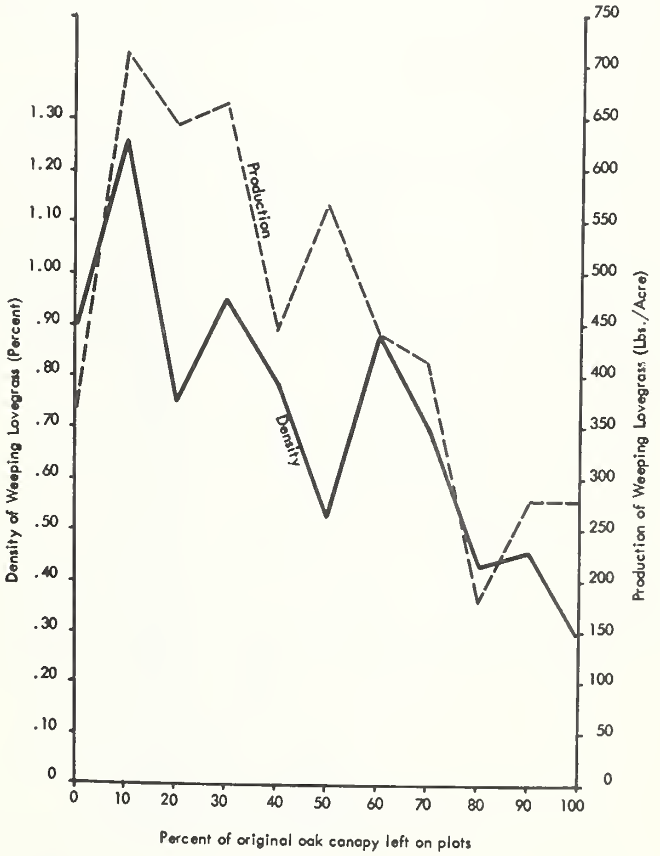


Figure 17. --Relation of weeping lovegrass to amount of oak. Both cover and herbage production of the 1-year-old weeping lovegrass decrease as residual oak canopy increases.

STREAMFLOW STUDIES IN CHAPARRAL

Streamflow measurements are now in progress on chaparral watersheds at elevations ranging from 3,500 to 6,500 feet and receiving from 16 to more than 25 inches of precipitation.

Records have been taken since the 1930's at Summit and Natural Drainages north of Roosevelt Lake. Since 1956, gaging stations have been installed at Whitespar and Mingus Mountain near Prescott, and at 3-Bar in the Mazatzal Mountains.

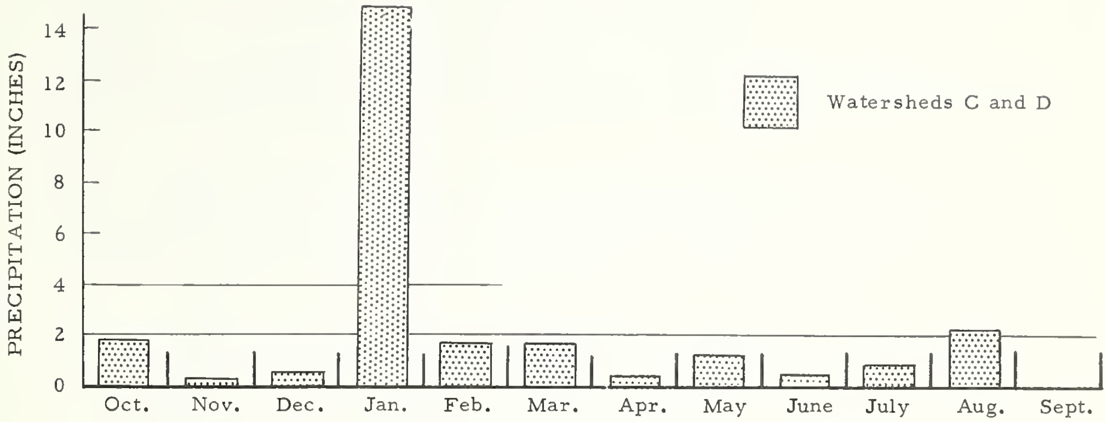
Measured annual water yields have varied from zero to 2.35 inches, depending on amount, seasonal distribution, and intensity of precipitation, and the nature of soil and plant cover. On typical chaparral watersheds, water yield occurs mainly during winter and spring as a result of cool-season precipitation.

Seasonal distribution of runoff at the Summit watersheds is unusual in that most of the runoff comes in the summer. These nine watersheds lie at 3,500 feet elevation in the lowest and most desertlike part of the chaparral type. Runoff has averaged 0.54 inch or 3.2 percent of the annual rainfall of 16.78 inches; nearly two-thirds of the annual runoff resulted from intense summer storms.

Average annual water yield from four Natural Drainage watersheds at Sierra Ancha Experimental Forest during the period 1935 to 1952 varied from 1.1 to 2.2 inches, or approximately 5 and 10 percent, respectively, of the annual rainfall (table 13). The Natural Drainages are at an elevation of 4,500 feet and have a mixed chaparral-semidesert grass vegetation. Water yields were highest on watersheds having the greatest amount of shallow quartzite soil, and were lowest on those having greatest amount of deep porous diabase soil. Under the grazing treatment applied, grass density was reduced but water yield did not change significantly.

Table 13.--Seasonal and annual water yield from Natural Drainage watersheds

Watershed	Winter			Summer			Total year		
	Rain	Yield		Rain	Yield		Rain	Yield	
	Inches	Inches	Percent	Inches	Inches	Percent	Inches	Inches	Percent
A	14.4	1.6	11	7.5	0.2	3	21.9	1.8	8
B	14.4	1.0	7	7.5	.2	3	21.9	1.1	5
C	14.9	2.0	13	7.1	.2	3	22.0	2.2	10
D	14.9	2.0	13	7.1	.2	3	21.9	2.2	10



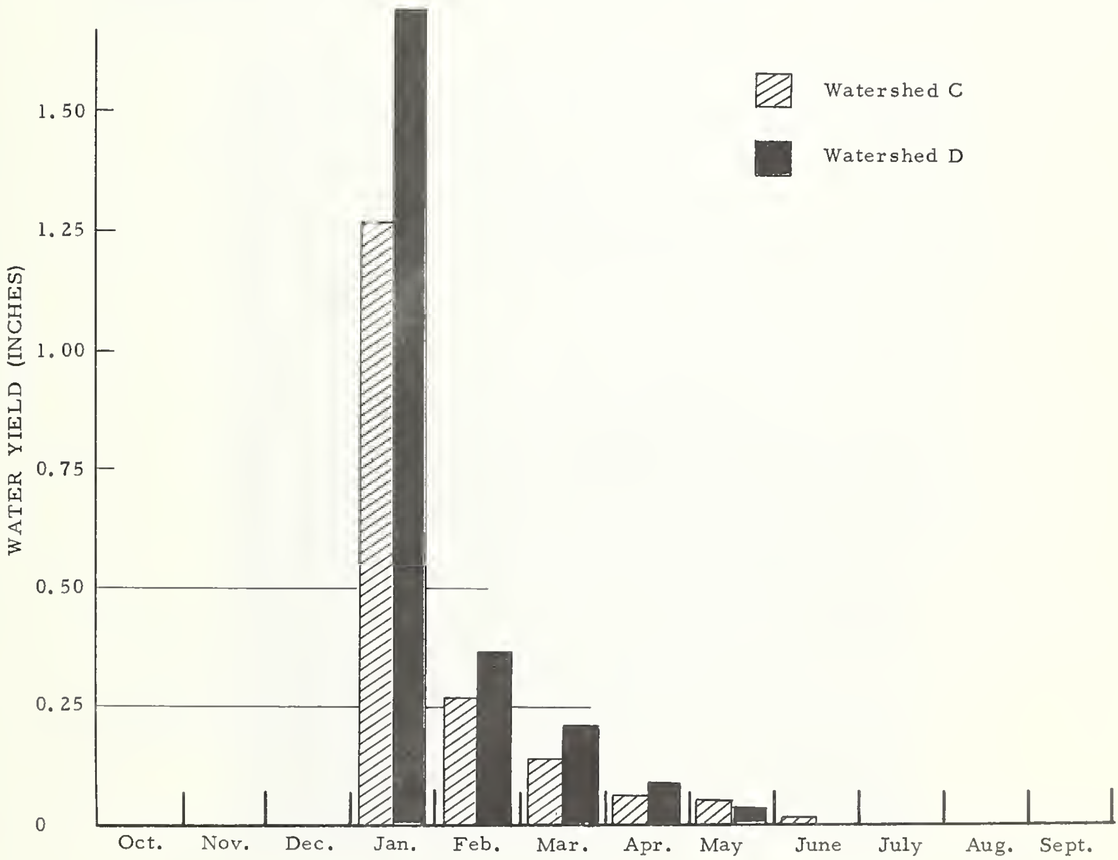


Figure 18.--Water yield in relation to precipitation on the 3-Bar watersheds in 1957.

Since 1956, water yields have been measured on four larger (50 to 274 acres) chaparral drainages within the 3-Bar Wildlife Area in the Mazatzal Mountains near Roosevelt Lake north of Globe. These watersheds (prior to the 1959 Boulder fire) supported dense, well-developed mixed oak chaparral developed on decomposed granite soils under a rainfall of more than 25 inches. They were selected as representative of areas where manipulation of plant cover for improvement in water yield and game habitat would be desirable.

During 3 years of measurements before the fire, water yields on 3-Bar watersheds C and D varied from 0.01 to 2.4 inches per year. Winter (October 1 to May 31) precipitation varied from 8.8 to 23.0 inches, as shown in table 14. There was no flow from watersheds A and B.

Table 14. --Three years' water-yield[1] data for 3-Bar watersheds

Watershed	Area	Period	1956-57			1957-58			1958-59		
			Precipitation	Water yield		Precipitation	Water yield		Precipitation	Water yield	
	Acres		In.	In.	Pct.	In.	In.	Pct.	In.	In.	Pct.
C	76	Winter	21.7	1.8	8	22.4	1.1	5	8.8	T[2]	T[2]
		Annual	25.1	1.8	7	31.3	1.1	4	8.8	T	T
D	50	Winter	22.0	2.4	11	23.0	1.4	6	9.3	0.4	4
		Annual	24.5	2.4	10	30.1	1.4	5	9.3	.4	4

[1] All yields were from winter precipitation

[2] Trace

Figure 19. --Part of the 3-Bar watersheds following the Boulder fire in June 1959. Area was completely burned and tops of shrubs were destroyed. Water and sediment measurements will be continued to learn what changes have been caused by the fire. Burned areas seeded to grass will be compared with those allowed to recover naturally.

Flows on watersheds C and D started in January in 1957 and in February in 1959. Early heavy rains started flows in late October in 1958. Flows on watershed D ceased in mid-May during 1957 and 1958, and in early March in 1959. On watershed C flows continued through to mid-June in 1957, mid-May in 1958, and late February 1959. The need for adequate periods of calibration prior to treatment of experimental watersheds in the chaparral type is clearly indicated by the variation between years and between watersheds, both in actual yield and in percent.

On the Whitespar watersheds (fig. 20) streamflow has begun earlier and continued longer into the summer than at 3-Bar; but total water yield has been smaller. First year's flow data for the period July 1958 to July 1959 are:

Watershed	Area (Acres)	Precipitation (Inches)	Water yield (Inches)	Water yield (Percent)
A	310	22.41	0.24	1
B	230	21.30	.17	1

Vegetation on Whitespar watershed consists mainly of mixed oak and mountainmahogany lying just below the ponderosa pine belt at an elevation of 5,800 to 7,100 feet.

Figure 20.--Stream-gaging station on Whitespar watershed B. Water stage recorders on 120° V-notch weirs were installed by June 1958 on two Whitespar watersheds and continuous records of precipitation and streamflow have been obtained since that time. San Dimas flumes with stage recorders for measuring high flows were completed in June 1959.

SEDIMENT

Because of the generally steep slopes, the nature of parent geologic material, the young immature soils, and the inherent scarcity of herbaceous plant cover, potential sediment movement rates on many chaparral sites are high. One of the primary research objectives has been to determine sources, manner of movement, and yield of eroded material. Bedload has been measured at all

gaged watersheds in sediment basins provided at each weir dam. Catches are measured after each storm if possible and regularly at the end of each water year. Profile stations have also been established and measured at some of the smaller watershed installations as routine procedure, as well as on the Pinal Mountain burn following a wildfire in 1951.

Sediment production as measured on unburned chaparral watersheds has been variable but generally low. On the 3-Bar watersheds only negligible amounts of sediment were trapped during the period 1956 to June 1959. The same was true at Whitespar and on Mingus A and B watersheds during 1958 and 1959. On the adjacent 46-acre Mingus C watershed, however, 500 cubic yards of sediment per square mile were yielded as a result of storms of 1.75 and 1.30 inches in August 1958.

In contrast, since the nearly complete destruction of aerial plant cover by wildfire on the 3-Bar watersheds in June 1959, large quantities of sediment have been trapped and measured at each of the four watersheds (fig. 21). At watershed B, which is representative, total sediment yield since August 1959 has amounted to more than 40,000 tons per square mile.

Figure 21.--After each major rain, following the wildfire of June 1959 on the 3-Bar area, weir ponds were filled and large volumes of sediment were captured in auxiliary basins. This delta, approximately 100 feet long and up to 5 feet deep, contains 4,187 cubic feet of material and represents a sediment yield of 2,100 tons per square mile from the 77-acre watershed C after the 2.15-inch rain of August 4, 1959.

CONTROL OR CONVERSION OF CHAPARRAL

Research in control of chaparral included use of chemicals, mechanical equipment, and fire.

Chemical Studies

Use of chemicals is the responsibility of the U. S. Agricultural Research Service under a cooperative arrangement with the Forest Service. This work is reported separately. Also, cooperative work with the University of Arizona in pilot testing of aerial application of herbicides on oak has been conducted since 1956.

Mechanical Control

Mechanical control of chaparral may be feasible on selected productive bottom land sites where soil is relatively deep and rockfree. During the summer of 1958, the Forest Service, the Agricultural Research Service, and the Caterpillar Tractor Company cooperated in testing a heavy root plow at the Tonto Springs Ranger Station near Prescott (fig. 22). Approximately 50 acres of mixed oak chaparral were plowed and simultaneously seeded to grass by use of an exhaust-operated seed hopper. Larger trees were uprooted with the bulldozer. First-year observations indicate that the root plow, which severed the plants 6 to 12 inches below ground level, was highly effective in eradicating all species of shrubs including the sprouting shrub live oak. The few shrubs which survived were either smashed and only partially severed, or were missed completely by the plow. Seeding success appears promising.

In this test a D-7 caterpillar was used, and indications are that a D-8 would be preferable. Costs, although not too meaningful where small tests are involved, appear to be about $20 per acre for plowing and seeding.

The evaluation of other promising types of heavy mechanical equipment will be continued at such times as tests can be arranged cooperatively with equipment companies and National Forest Resource Management.

Figure 22. --Root plow being tested as means of controlling shrubs and preparing seedbed on mixed oak site near Prescott, Arizona.

LABORATORY AND GREENHOUSE INVESTIGATIONS ON THE CHEMICAL CONTROL OF CHAPARRAL

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HIGHLIGHTS

Laboratory and greenhouse studies have been started by the Agricultural Research Service to gain a better understanding of factors affecting growth of shrub live oak seedlings and susceptibility of seedlings to herbicides. The interest in growth characteristics stems in part from the fact that plants are usually most susceptible to herbicides when they are growing rapidly.

Growth was most rapid under conditions of high temperature and partial shade; growth was poorest when it was cool and sunny. Many shrub live oak seedlings grow according to a definite rhythm, with surges in growth rate at monthly intervals.

Emphasis so far has been on soil-applied herbicides rather than foliar sprays, although further testing of sprays is planned. Soil applications of eight pelleted and granular herbicides were made at rates varying from 2 to 16 pounds per acre. Under greenhouse conditions with seedling plants, 4 or more pounds of fenuron per acre were most effective, giving 100 percent kill in 20 weeks. Monuron was about three-fourths as effective as fenuron; the growth regulators (2, 4-D, etc.) were roughly half as effective; and simazine had practically no effect at all. The striking effect of 2, 3, 6-TBA was one of stunting.

LABORATORY AND GREENHOUSE INVESTIGATIONS ON THE CHEMICAL CONTROL OF CHAPARRAL[4/]

by

Edw~~ard~~in A. Davis, Plant Physiologist[5/]

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A research program for the control of chaparral in Arizona was initiated in 1958 by the Agricultural Research Service in cooperation with the Forest Service of the U. S. Department of Agriculture. This research is being conducted by the Crops Protection Research Branch of the Crops Research Division.

Laboratory and greenhouse studies are being conducted to evaluate herbicides and gain physiological information that may aid in controlling chaparral under field conditions. In these studies major emphasis is being placed on shrub live oak.

Greenhouse investigations can provide information on the toxicity of chemicals against test plants under conditions which provide maximum opportunity for chemical effectiveness. Accordingly, chemicals can be evaluated without some of the limitations that might reduce their effectiveness in the field. Greenhouse studies also provide a means for evaluating chemicals available in only small quantities.

GROWTH OF SHRUB LIVE OAK SEEDLINGS

Temperature and Light

Seedling growth experiments indicate that shrub live oak thrives under hot conditions with partial shade (fig. 23). Hot, sunny conditions are slightly less favorable; whereas warm, shady conditions and cool sunny conditions are considerably poorer. It was also observed that temperatures in excess of 100° F. with full sun reduce growth drastically. However, many shrub live oak seedlings withstand excessive summer heat and full sun, provided they have enough moisture. These results supply information needed for growing seedlings for experiments. They are in agreement with the observation that at lower elevations, where temperatures are high and moisture may be limiting, shrub live oak tends to be more abundant on north-facing slopes, while at higher elevations it is denser on south-facing slopes.

Growth Rhythm

There are numerous examples of organisms whose various processes proceed in definite rhythmic patterns. The growth of many shrub live oak seedlings also proceeds in a definite rhythm; that is, growth occurs intermittently or in "flushes" (fig. 24).

4/ Cooperative investigations of the Crops Research Division, Agricultural Research Service, and the Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture.

5/ Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Tempe, Arizona.

Figure 23. --Growth of shrub live oak seedlings under various environmental conditions. Night conditions were the same for all experiments; the average minimum night temperature was 61°F. The general daytime conditions listed in the graph are characterized by the following average maximum temperatures and light intensities: hot-shady, 97°F., 2,800 ft. c.; hot-sunny, 97°F., 10,000 ft. c.; warm-shady, 88°F., 2,000 ft. c.; and cool-sunny, 76°F., 12,000 ft. c.

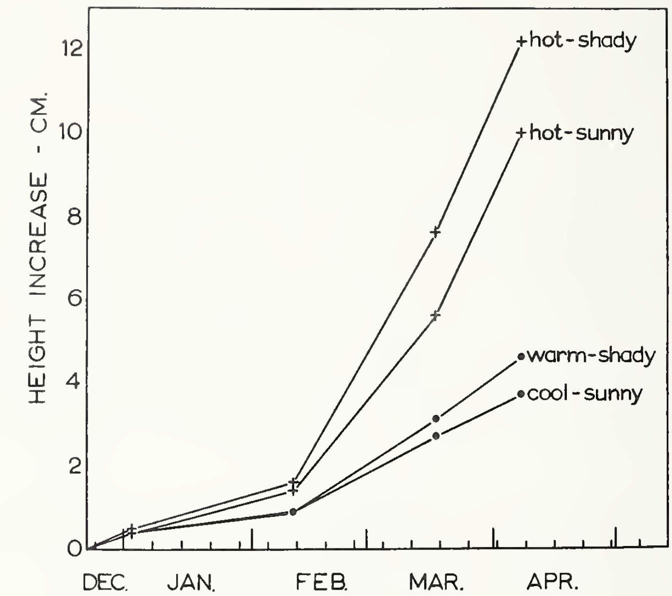
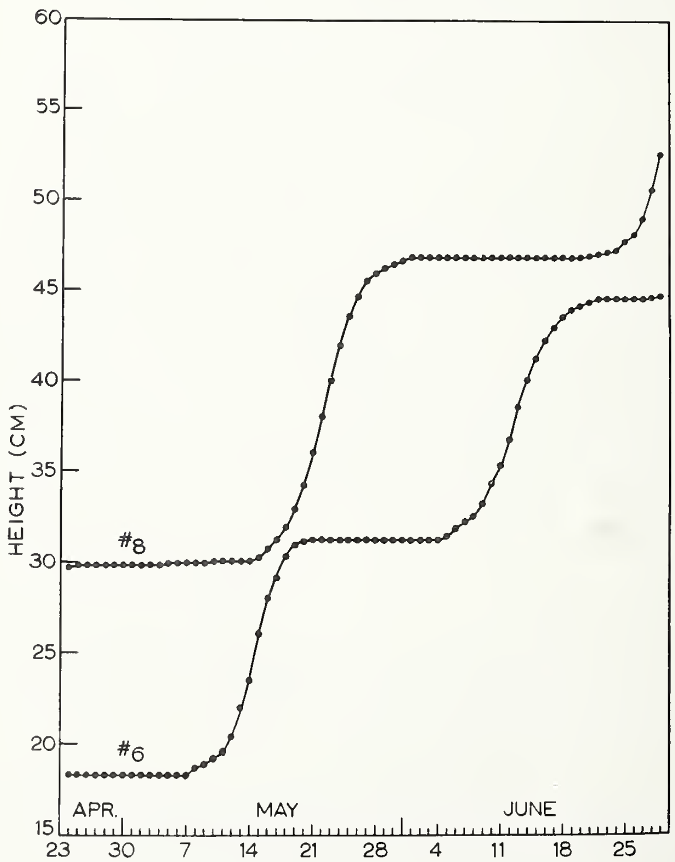


Figure 24. --Typical growth curves of shrub live oak seedlings illustrating the rhythmic growth pattern.



All seedlings do not exhibit the same pattern, nor in a group of seedlings do all grow at the same time. Since this rhythmic growth pattern proceeds under conditions of adequate moisture and nutrients, it would appear to be related to basic mechanisms within the plant. The interval between "flushes" during which growth ceases or slows down may be caused by the accumulation of an inhibitor or the exhaustion of some essential factor. Similar lags in growth can also be induced by unfavorable conditions of moisture, nutrients, and temperature.

Rapidly growing plants are usually more susceptible to herbicides than those that are not growing or are growing poorly. Herbicide effectiveness may then be related to this rhythmic growth process.

SOIL-APPLIED HERBICIDES

One reason why shrub live oak has been difficult to control is that it is capable of profuse sprouting from its buried crown region. Single foliar applications may kill existing foliage, but generally they have not prevented the development of crown sprouts. Some methods that show promise of overcoming this problem are repeated foliar sprays, applications of granular and pelleted herbicides to the soil, and high-volume basal sprays; however, only the first two of these methods are practical for large areas. Soil applications of granular and pelleted herbicides, particularly the substituted ureas such as 3-phenyl-1, 1-dimethylurea (fenuron), have shown considerable promise against a variety of brush and tree species. Pelleted or granular herbicides can be applied conveniently by hand broadcasting, by ground equipment, or by aerial application.

Rainfall enhances the action of most soil-applied herbicides by moving the herbicide into the root zone where maximum response is desired. Other factors that affect the results of soil applications are soil type and composition, water solubility of the chemical, adsorption of the chemical on soil particles, losses by leaching, chemical and microbial decomposition, volatility, and photodecomposition.

A greenhouse experiment was conducted with 3-month-old shrub live oak seedlings to test toxicity of a number of experimental granular and pelleted herbicides. The seedlings were grown in gallon containers in a loamy sand top soil obtained from a chaparral site. The seedlings were about 6 inches tall when the granules and pellets were sprinkled on the soil surface. Large granules and pellets were crushed before they were applied in order to obtain a more uniform distribution of the herbicide. The herbicides that were evaluated are shown in table 15. Applications were made on December 31, 1958, when the plants were growing very slowly. After the applications, 1/4 inch of water was added to the soil. Thereafter, known amounts of water were applied regularly to maintain adequate moisture for growth and to leach the herbicides into the soil. After 20 weeks, 17.5 inches of water had been applied in 1/4-, 1/2-, and 1-inch increments.

The seedlings responded very slowly to the herbicides (table 15). Five weeks after application only slight injury was apparent. At this time, monuron appeared to stimulate growth. The plants seemed greener, lusher, and in general healthier than untreated check plants. Later, however, typical symptoms of monuron injury developed. Marginal leaf necrosis progressed inward until the entire leaf was dead. After 9 weeks the effects of the chemicals were more pronounced but were still incomplete.

Table 15. --Effect of soil-applied herbicides on shrub live oak seedlings. (Herbicides were applied December 31, 1958, and evaluated in 1959.)

Treatment and amount of active ingredient	Visual estimates of top injury after-- 5 weeks (Feb. 4)	9 weeks (Mar. 4)	20 weeks (May 20)	Height growth reduction after 20 weeks (May 20)	Plants dead after 20 weeks (May 20)
	- - - - - - - - - - -	- - Percent - -	- - - - - - - - -		
Monuron pellets [3-(p-chlorophenyl)-1, 1-dimethylurea]					
2	0	2	30	32	40
4	0	10	45	46	43
8	0	25	50	62	84
16	0	80	100	80	100
Fenuron pellets [3-phenyl-1, 1-dimethylurea]					
2	5	25	85	60	76
4	35	85	100	87	100
8	15	85	100	78	100
16	20	95	100	79	100
Monuron-TCA or Urox granules [3-(p-chlorophenyl)-1, 1-dimethylurea trichloroacetate]					
2	0	20	55	62	56
4	0	25	70	58	56
8	0	20	100	78	96
16	2	20	99	79	80
2, 3, 6-TBA granules [2, 3, 6-trichlorobenzoic acid]					
2	0	2	20	70	18
4	10	10	68	98	60
8	5	30	72	97	80
16	5	40	78	97	72
Simazine granules [2-chloro-4, 6-bis(ethylamino)-s-triazine]					
2	0	2	0	19	27
4	0	0	0	0	0
8	5	10	10	24	28
16	0	2	10	39	11
2, 4-D ester granules [butoxy ethanol esters of 2, 4-dichlorophenoxyacetic acid]					
2	5	0	0	23	44
4	10	30	20	58	50
8	20	50	52	64	66
16	15	80	100	100	100
2, 4, 5-T ester granules [2, 4, 5-trichlorophenoxyacetic acid]					
2	5	0	0	34	32
4	5	5	45	62	46
8	10	40	52	61	70
16	15	50	85	94	86
Silvex ester granules [2-(2, 4, 5-trichlorophenoxy) propionic acid]					
2	5	5	10	65	44
4	5	5	35	43	58
8	2	20	48	78	56
16	2	45	88	97	72

Twenty weeks after treatment the results of the study were fairly clear, but the effects of all chemicals were not final (fig. 25). At this time the herbicides were evaluated in terms of percent reduction in plant height growth and percentage of plants dead (table 15). Clearly, fenuron was the most effective soil-applied herbicide evaluated. At 4 pounds per acre and higher it gave complete control, being more effective than monuron or monuron-TCA. The superiority of fenuron over monuron is probably due in large part to its greater solubility in water; the solubility of fenuron is 2,900 parts per million while that of monuron is 230 p.p.m. Also, fenuron is less readily adsorbed on the soil particles.

The 2,3,6-TBA stunted growth. For many weeks rates as low as 2 pounds per acre inhibited growth completely. Eventually the seedlings that received the 2-pound rate commenced to grow. Branching was profuse as the result of injury to the terminal buds and the developing shoots were severely malformed (fig. 26).

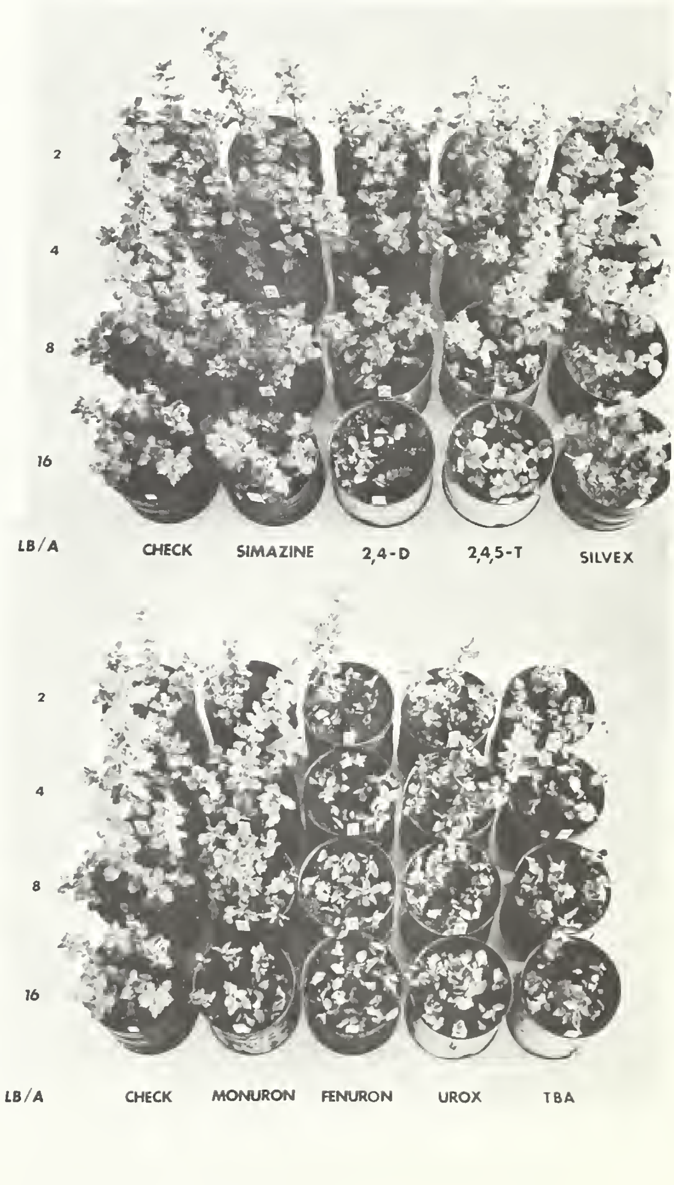


Figure 25.--The influence of several granular and pelleted herbicides on shrub live oak seedling 20 weeks after soil treatment. 2,4-D, 2,4,5-T, and silvex were applied as the butoxy ethanol esters. A total of 17.5 inches of water was applied in 1/4- to 1-inch increments.

Figure 26. --Malformation of shrub live oak seedlings 22 weeks after a granular application of 2, 3, 6-TBA at the rate of 2 pounds of active ingredient per acre.

Not until 6 months after treatment did normal leaves begin to appear. Although the killing effect of 2, 3, 6-TBA was not outstanding in this experiment, its stunting effect was potent and long lasting. After 6 months the seedlings treated at rates of 4 pounds per acre or more were still nearly completely inhibited.

Simazine had very little effect on shrub live oak, while the growth regulators 2, 4-D, 2, 4, 5-T, and silvex had low orders of activity. The 2, 4-D, which gave complete control at 16 pounds per acre, was superior to 2, 4, 5-T or silvex, which were about equally effective.

After 20 weeks this experiment indicated that of the several herbicides tested, fenuron offers the greatest promise of controlling shrub live oak by means of a soil application. 2, 3, 6-TBA is also of particular interest.

Although shrub live oak seedlings are susceptible to fenuron, it remains to be seen what effect fenuron will have on mature field plants.

FOLIAR APPLICATIONS OF HERBICIDES

Foliar applications of herbicides do not directly depend on rainfall and therefore have an inherent advantage over soil applications in low rainfall regions. Thus far, permanent control of shrub live oak with foliar sprays has met with little success. A laboratory turntable spray chamber was built to study the foliar-application approach in the laboratory and greenhouse. This apparatus will permit the evaluation of chemicals at known rates.

ACKNOWLEDGMENTS

Grateful acknowledgment is given to the following companies that supplied chemicals for these investigations: monuron and fenuron pellets and 2, 3, 6-TBA granules, E. I. duPont deNemours & Co., Inc.; monuron-TCA granules, General Chemical Division, Allied Chemical Corporation; simazine granules, Geigy Chemical Corporation; 2, 4-D, 2, 4, 5-T, and silvex granules, Amchem Products, Inc.

FIELD INVESTIGATIONS ON THE CHEMICAL CONTROL OF CHAPARRAL

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HIGHLIGHTS

Field tests of herbicides have been made by the Agricultural Research Service in conjunction with the laboratory and greenhouse tests previously described. Again, tests have been limited to shrub live oak.

Because field tests have been in progress for only 10 months, it must be stressed that results are strictly preliminary. Complete killing of individual oak plants has not been observed as a result of field applications. In contrast, greenhouse applications actually killed seedlings.

Of the foliar herbicides tested in the field, the phenoxy compounds and chlorobenzoic acid derivatives have been most effective against shrub live oak. The phenoxy compounds killed most of the leaves within a month; however, the plants recovered and put out apparently normal sprouts. The chlorobenzoic compounds did not kill the leaves and stems but slowed growth drastically and caused malformation. Tests of herbicide carriers indicate that at least 5 percent oil in emulsion is needed for optimum control.

Soil-applied, granular and pelleted herbicides were tested, including monuron, fenuron, and simazine, as well as the phenoxy and chlorobenzoic herbicides. Of these, fenuron was most effective, achieving complete, though temporary, defoliation. The chlorobenzoics had a stunting effect, both as a soil treatment and as a foliar spray.

In attempts to dry out shrub live oak as an aid to prescribed burning, leaf moisture but not twig moisture was lowered appreciably.

New tests not yet evaluated include timing of application within seasons, various herbicide formulations, and retreatment.

FIELD INVESTIGATIONS ON THE CHEMICAL CONTROL OF CHAPARRAL[6/]

by

Donald T. Lillie, Research Agronomist[7/]

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Initial field investigations on chemical control of chaparral are being concentrated on shrub live oak. This species is more common than any others in the type and is believed to have relatively low desirability as browse. As studies on shrub live oak progress, the program will be expanded to include specific experiments on other shrub species. It will be possible to get some information on the reaction of these associated species to herbicides by watching what happens to them on the treated shrub live oak plots.

If shrub live oak is to be controlled with herbicides, some method must be devised to concentrate sufficient herbicide in the crown area of the plant to impair sprouting significantly. An herbicide to which oak is particularly susceptible, which penetrates the plant readily, and which is translocated in quantity, would be ideal. Eventually an herbicide-screening program in the laboratory is planned. However, as the chances that screening will reveal such an ideal chemical are remote, the immediate task is to explore ways and means of getting better results with the herbicides at hand. To this end the following investigations have been adopted:

1. Field evaluation of several herbicides at different rates of application.
2. Application of herbicides at various seasons of the year chosen to correspond with various growth stages.
3. Timing of application within a single growth stage of shrub live oak.
4. Testing of various formulations of the same herbicide for activity on shrub live oak.
5. Testing of water as compared with various oil-in-water emulsion rates as carriers of a given herbicide.
6. Evaluation of re-treatments and timing of re-treatments as these practices affect control.
7. Application of granular or pelleted forms of herbicides to the soil surface.
8. Chemical desiccation of shrub live oak as an aid to prescribed burning.

Each of these lines of investigation will be discussed separately and certain results will be presented. It must be emphasized that these results reflect preliminary observations only and final results of the experiments may differ greatly from these preliminary data.

6/ Cooperative investigations of the Crops Research Division, Agricultural Research Service, and the Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture.

7/ Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Tempe, Arizona.

FIELD EVALUATION OF HERBICIDES

A number of foliar-applied herbicides were tested in the field to evaluate their relative merit for the control of shrub live oak (fig. 27). These tests have been under way only 10 months. It is too soon to predict what degree of control might eventually be attained. These tests and all others, have been evaluated only in terms of percent apparent control. Complete killing of individual oak plants was not observed.

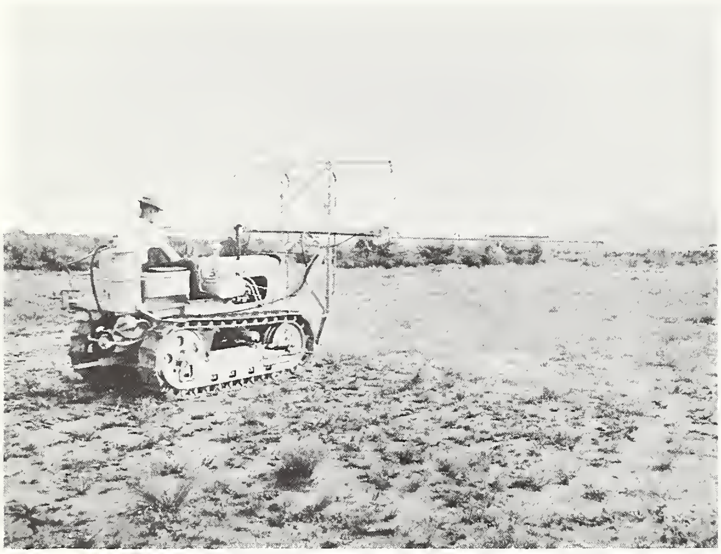

Figure 27. --Foliar applications of herbicides to plot areas were made by a 25-foot spray boom mounted on the crawler tractor. This sprayer was designed to provide critical control of pressures. Variation of the operating pressure along with ground speed and nozzle-orifice size allowed a wide selection of application volumes; however, in these experiments all applications were made at a volume of 20 gallons per acre.

There will be no attempt here to enumerate the compounds or characterize them chemically. It is sufficient to say that two groups of herbicides appear to be superior to the others. These groups are the phenoxy compounds, and a relatively newer class of compounds, the chloro-benzoic acid derivatives.

The phenoxy compounds resulted in a rapid killing of leaves. Less than a month after application the oak plants appeared to be severely damaged. Although nearly complete leaf killing and some stem killing occurred, the plants recovered and sprouts from the stems and crowns were apparently normal. The chloro-benzoic compounds, on the other hand, resulted in comparatively little leaf and stem killing. However, their action was more chronic than acute, and 10 months after treatment there was very little growth and that was badly malformed.

All these compounds were applied at two or more rates. Rates were deliberately set at a rather high level to insure that no active compounds would be missed. The more active compounds will be selected for testing at a wide range of rates to reveal the lowest effective rate of application.

SEASONAL APPLICATION OF HERBICIDES

The occurrence in Arizona of two rainy seasons results in two periods of relative abundance of moisture followed by periods of relative drought. Logically the plants should grow slowly if at all during the dry periods and relatively fast when water is available, provided other environmental influences, particularly temperature, are favorable. These four periods of the year may be considered roughly equivalent to growth stages of the plant.

Many plants have stages in their life cycle when they are more sensitive to herbicides than at other times. Sensitive stages generally coincide with periods of new cell or tissue development. However, some excellent results have been reported on woody species with dormant-season sprays.

The seasonal tests were originally scheduled to be applied in each of four seasons of the year on burned-over and nonburned-over shrub live oak. To date only two season tests have been applied and those tests placed on nonburned oak have since been destroyed by fire. However, preliminary data were obtained prior to burning (table 16).

Table 16. --Percent apparent killing of shrub live oak on unburned and previously burned plots at various intervals after two dates of treatment with phenoxy and chloro-benzoic herbicides

Treatment date and name of herbicide[1]	Apparent killing on--			
	January 28, 1959		June 16, 1959	
	Burned plots	Unburned plots	Burned plots	Unburned plots
	Percent			
September 30, 1958				
2, 4, 5-T	98	97	15	81
Silvex	93	96	36	90
TBA	26	24	13	30
PBA	67	50	19	40
March 12, 1959				
2, 4, 5-T			43	84
Silvex			50	81
TBA			5	69
PBA			9	78

[1] 2, 4, 5-T = 2, 4, 5-trichlorophenoxy acetic acid
Silvex = 2(2, 4, 5-trichlorophenoxy)-propionic acid
TBA = dimethylamine-2, 3, 6-trichlorobenzoate
PBA = polychlorobenzoic acid

These data were taken too soon after treatment to show the relative merits of treatment during the two seasons. Sufficient time had not elapsed for the full expression of the herbicidal effects. However, these data illustrate that a sufficient time lapse must occur before reporting upon the efficiency of herbicidal applications to woody perennials. When burned-over plots were treated with 2, 4, 5-T in September there was apparent killing of 98 percent

the following January, but by June the plants had recovered to such an extent that only 15 percent killing was apparent. Apparent killing on TBA plots had dropped in that interval from 26 to 13 percent, but there was only a small amount of malformed growth (fig. 28). Growth on the 2, 4, 5-T plots was normal.

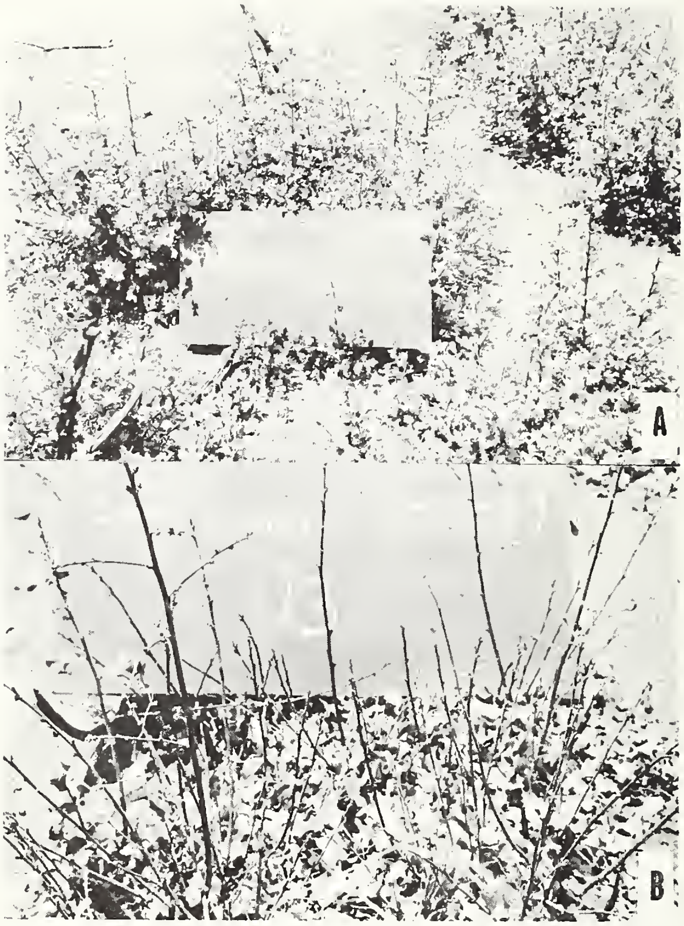

Figure 28. --

A, Untreated shrub live oak plot.

B, Plot treated with TBA amine showing restricted malformed growth.

Treatment of the sprouts on the burned-over plots resulted in some topkill. However, when new sprouts appeared the plots looked much as they did before treatment. When the unburned plants were topkilled, the sprouting resulted in a much smaller ratio of topkilled material to new sprouts. The different ratio accounts for the much higher apparent damage readings on the unburned plots.

TIMING WITHIN SEASONS

This series of tests was designed to determine whether shrub live oak could be more effectively controlled at a particular stage of development. On the basis of research work on other woody species, it seemed logical that oak might be most susceptible to herbicides in the spring when the plant is growing rapidly.

Applications of 2, 4, 5-T and silvex were made at various intervals to single bush plots. Notes were taken on growth and stage of development of shrub live oak and skunkbush sumac at the time of each application.

Preliminary records of apparent damage have been taken, but it is too soon after treatment to draw conclusions from these data. As observed in other tests with these herbicides, extensive leaf killing resulted.

VARIOUS FORMULATIONS OF HERBICIDES

Studies were initiated to evaluate the comparative effectiveness of formulations of 2, 4, 5-T and silvex for the control of shrub live oak. The formulations applied were a standard low-volatile ester in an oil-water emulsion, a standard low-volatile ester formulated to improve penetration when applied in water without oil, and the amine salts of 2, 4, 5-T and silvex in water.

Results from these tests are not available as yet.

COMPARISONS OF HERBICIDE CARRIERS

Penetration of the herbicide into the plant is important in the control of woody species. Many investigators have found that herbicides carried in an oil-water emulsion penetrate better than herbicides emulsified in water alone. Wetting agents or spreaders have also been found to improve control.

A single rate of 2, 4, 5-T (3 pounds per acre) carried by water and by oil-water emulsion ratios of 5, 10, 20, and 40 percent oil was applied without additional wetting agent, with Colloidal Chemical's "X-77"[8/] and with General Chemical's "Plyac."[8/] Preliminary results (table 17) indicate that 5 percent oil in the emulsion improved control, but there was no additional improvement with higher ratios. Addition of the wetting agents had no significant effect on control when oil emulsions were used.

Table 17. --Percent apparent killing of oak 9 months after treatment with 3 pounds per acre of 2, 4, 5-T carried by various oil-water emulsion ratios with and without wetting agents

Wetting agent	Apparent killing by indicated percentage of oil in emulsion					
	0	5	10	20	40	Average
	Percent					
None	21	74	69	72	55	58
Plyac (3 ml. /gal.)	39	67	82	82	74	70
X-77 (3 ml. /gal.)	41	65	66	68	77	63
Average	34	69	72	74	69	

8/ Commercial names were used for purposes of identification only and their use does not constitute an endorsement.

EFFECT OF RE-TREATMENT AND ITS TIMING

It was apparent that a single application of phenoxy herbicides would not completely kill shrub live oak. Therefore, a series of tests to evaluate re-treatments at various intervals was begun.

Initial applications of phenoxy and chloro-benzoic herbicides have been made. The same plots will be re-treated 6, 12, and 18 months after initial treatment. In addition, another series of plots will be re-treated 6 and 18 months (total of 3 applications) after initial application. Still another series of plots will be treated each spring, each fall, and both spring and fall until the oak plants have been completely killed.

No results are available yet.

APPLICATION OF GRANULAR AND PELLETED HERBICIDES TO SOIL

Foliar applications of herbicides depend upon translocation, which is thought to proceed primarily in the inner bark, to get the chemical into the below-ground portion of the plant. This type of transport is rather slow and often unsatisfactory.

Herbicides may be applied to the soil and be leached into the soil by rainfall. There they may be absorbed by the roots of plants as are nitrogen, phosphorus, and other mineral nutrients. The herbicides are then swept along with the sap stream and rapidly carried throughout the above-ground portions of the plant. Absorption by the roots and translocation of herbicides through the xylem of the plant in some respects are much more efficient processes than those involved when herbicides are absorbed through the stems and leaves of the plant and translocated downward. These principles have long been recognized and utilized in the application of herbicides for soil sterilization and preemergence weed control.

In addition to the advantages of improved absorption and translocation there are advantages in applying granular or pelleted herbicies rather than sprays. (1) They require no mixing and may often be delivered by aircraft from preexisting seeding and fertilizer spreading equipment. (2) They greatly decrease the drift hazard and may be released at much higher altitudes. (3) They can be applied satisfactorily in stronger winds. (4) They are generally formulated in more concentrated form and therefore permit a larger payload.

Although the advantages of soil treatments are many, it should be remembered that this type of application brings a whole battery of new chemical, physical, and biological processes into play.

Some of these problems are photodecomposition, adsorption of herbicides onto soil colloids, solubility of the herbicide molecule, and microbial decomposition. But most important, rainfall must be sufficient to leach the herbicide into the soil.

Tests have been applied to evaluate granular and pelleted herbicides for the control of shrub live oak. In addition to 2, 4-dichlorophenoxy acetic acid (2, 4-D), 2, 4, 5-T, silvex, and the chloro-benzoic (TBA acid and amine) herbicides previously mentioned, two different classes of herbicides were applied.

They are 3-(p-chlorophenyl)-1, 1-dimethylurea (monuron), 3-(phenyl)-1, 1-dimethylurea (fenuron), 3-(p-chlorophenyl)-1, 1-dimethylurea trichloroacetate (monuron-TCA), and 2-chloro-4, 6-bis-(ethylamino)-s-triazine (simazine).

These granular and pelleted herbicides were applied in December 1958. Preliminary evaluations were made in June 1959. The chlorobenzoic acid herbicides and fenuron, monuron, and monuron-TCA had a considerable effect on the oak (table 18). Fenuron and to a lesser extent monuron succeeded in defoliating the plants almost 100 percent; however, the plants later refoliated and the leaves appeared normal. The chlorobenzoics (TBA), on the other hand, were not as effective in defoliating the plants, but the plants showed almost no growth and some smaller branches were dead (figs. 29 and 30). Simazine, 2, 4-D, 2, 4, 5-T, and silvex have been ineffective up to this time.

Table 18. --Percent apparent control of shrub live oak on June 24, 1959, on plots treated December 28, 1958, with pelleted or granular forms of various herbicides

Treatment	Apparent killing by indicated rate per acre			
	4 pounds	8 pounds	16 pounds	Average
	Percent			
2, 4-D	3	4	13	7
2, 4, 5-T	2	4	5	4
Silvex	3	3	7	4
Fenuron	51	31	42	41
Monuron	16	42	51	36
Monuron-TCA	19	57	79	52
TBA acid	30	52	57	46
Simazine	2	2	6	3
TBA amine	55	54	54	54
None (check)	2	2	2	2

Figure 29. --Plot treated 6 months previously with 8 pounds per acre of fenuron. Leaves on bush are nearly all regrowth.

Figure 30. -- Plot treated 6 months previously with 8 pounds per acre of TBA amine. Nearly all leaves and some branches are dead.

CHEMICAL DESICCATION OF SHRUB LIVE OAK

Prescribed burning alone or possibly followed by chemical treatment may prove to be a valuable tool for the general control of chaparral species in Arizona. Controlled burning is at present difficult or hazardous because of difficulties in containing a prescribed fire during a dry period and the low flammability of chaparral during a damp period or "off" season.

Through chemical desiccation of brush, it may be possible to burn during a period of low fire hazard, thus the danger of a wildfire resulting from prescribed burning on designated areas is minimized. Chemical desiccation offers the further possibility of burning wide firebreaks in a season of low fire hazard. The firebreaks would allow prescribed burning of large areas under moisture conditions otherwise too hazardous to allow burning.

Several desiccants or herbicides were applied, each at two application rates to single bush plots, on March 26, 1959. Samples of leaves and small twigs were taken 1, 3, and 6 weeks after treatment. Samples were taken on four sides of the treated bush and placed in glass jars then tightly capped. The plant material was dried 24 hours at 105°C., and moisture loss recorded as percentage of dry weight.

Chemicals applied were 2, 4-D at 1 and 2 pounds per acre, silvex at 1 and 2 pounds per acre, 4, 6-dinitro-ortho-secondary-butylphenol (DNBP) at 4 and 8 pounds per acre, chlorate-borate at 20 and 40 pounds per acre, and 1, 1'-ethylene-2, 2'-dipyridilium dibromide (FB. 2) at 1 and 2 pounds per acre. The chlorate-borate and FB. 2 were applied in water; and the rest were applied in diesel oil. All treatments contained a wetting agent at 2 milliliters per gallon.

Single-bush applications were made, also at 20 gallons per acre, from a 2-1/2-gallon hand sprayer fitted with a 6-foot boom and a pressure gage. No attempt was made to apply a specific volume of spray per bush, but a pass was made over the area occupied by the bush with the sprayer calibrated to deliver 20 gallons per acre at approximately the speed at which the operator would walk.

It may be seen that none of the treatments lowered the moisture content of the twigs below that of the check (fig. 31). Several of the treatments, however, lowered the moisture content of the leaves appreciably. DNBP and chlorate resulted in most rapid desiccation, but severe defoliation accompanied the desiccation. It seems that fire would proceed more effectively with dry leaves still attached to the stems, but this hypothesis has not been tested at this station.

2, 4-D and silvex lowered the moisture content more slowly, but the plants retained their leaves much better and did not refoliate as did the DNBP- and chlorate-treated plants.

During a prescribed fire that included some of the plots treated in the season test, it was observed that the fire carried much better in the treated plots than outside the plot area.

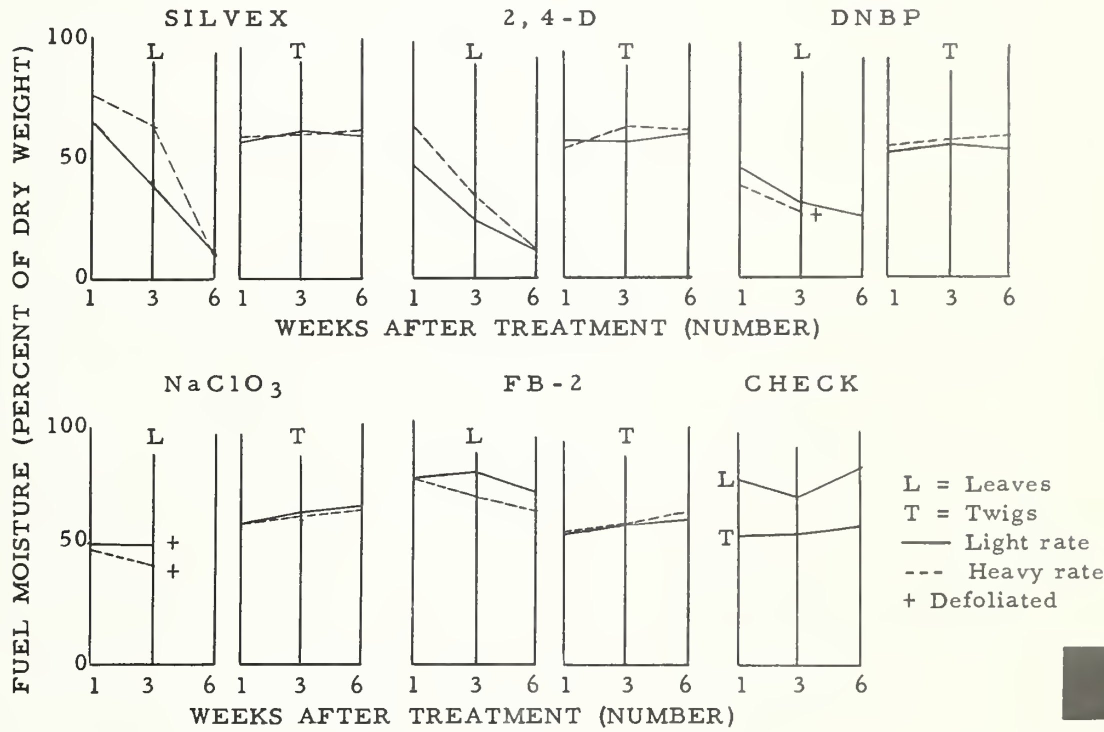

Figure 31. --Graphic results of desiccation study. Samples of leaves and small twigs taken 1, 3, and 6 weeks after treatment, ovendried 24 hours at 105°C., and moisture loss presented as percentage of dry weight.

WATERSHED MANAGEMENT RESEARCH IN STREAM-BOTTOM VEGETATION

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HIGHLIGHTS

Phreatophytes are the main concern of research on stream bottoms. These plants grow with their roots in or near the water table. The first objective of current research is to learn how to control spread of tamarisk (saltcedar) and how to replace it and other undesired plants with more useful vegetation. Plants which have been studied include tamarisk, seepwillow, arrowweed, and Bermudagrass.

Water use has been estimated with the aid of an apparatus that measures water transpired by plants enclosed in plastic tents. Water-vapor loss from tamarisk-Bermudagrass plots varied from about 60 to 130 grams per minute, depending on tamarisk density. Loss from Bermudagrass alone was about 46 grams per minute.

In conjunction with tests of mechanical and chemical treatments, studies have been made of the life history of phreatophytes to learn whether the plants may be susceptible to environmental control measures.

Temperature was found to play an important role in seed viability. Tamarisk seed produced in the spring does not carry over to germinate the following season; however, some summer-produced seed does carry over. Tamarisk seed stored at 72°F. to 80°F. retained its viability twice as long as seed stored at 95°F. to 105°F. At 40°F., viability was retained for more than a year.

Moisture also has an important influence on germination, for tamarisk seed requires free water or wet soil for germination. The plants become established by stranding on warm moist soil in a humid environment. They develop slowly and are killed by drying or flooding during the first few weeks of life.

Hydraulic excavation of phreatophyte root systems revealed that tamarisk and seepwillow have taproots, whereas arrowweed has a lateral root system. Tamarisk roots do not sprout--an important factor in control. Stem cuttings do sprout, however, and produce vigorous roots and shoots at all times of the year except the fall.

In tests of the effect of grazing on tamarisk, it was found that cattle browse heavily on vigorous tamarisk shoots, which grow in open stands mixed with grass. Shoots protected from grazing grew 4 feet in 5 weeks, while grazed sprouts reached a height of only 1 foot.

For effective and permanent mechanical control, the root crowns must be severed from the root system. In one test, the Fleco root plow mounted on a D-7 tractor proved to be a cheap and effective method for controlling tamarisk. The plow was pulled 12 to 18 inches below the soil surface.

In tests of chemical-control measures three or more applications of herbicide over a period of 2 years were required to eradicate mature tamarisk. Silvex was more effective than 2, 4-D or 2, 4, 5-T.

WATERSHED MANAGEMENT RESEARCH IN STREAM-BOTTOM VEGETATION

by

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Phreatophytes are plants that grow where their roots can reach the water table or the capillary fringe above the water table. They are found on streambanks, flood plains, and desert washes throughout the arid West. In the presence of a perennial water supply, this vegetation uses water that might otherwise be available for more beneficial uses. In addition, phreatophytes form barriers to flood flows, increasing flood stage and deposition of sediment.

Several agencies are participating in phreatophyte removal and research to improve present control methods (Thompson, 1957). In 1955, the Forest Service started a research program on phreatophytes (Horton, 1959). This work, centered at Tempe, Arizona, is designed to supplement the programs of other agencies. It aims to determine how to replace phreatophytes with plants less demanding in their use of water or of greater economic use. This requires ecological studies of phreatophyte associations and their component species to provide information needed for control. Water used by the different species and associations is investigated to aid in selecting the most desirable species.

Research effort of the Forest Service was first centered on fivestamen tamarisk, which has spread rapidly since its introduction from the Mediterranean region. Many thousands of acres of flood plain and river banks in the Southwest are now occupied by this species. Priority was given to learn how this species might be kept from invading new areas.

WHERE PHREATOPHYTES GROW

In Arizona, riparian sites from the high mountains to the desert regions are occupied by phreatophytes. Associations of phreatophytes tend to intergrade, but three broad phreatophyte situations can be distinguished.

The most noteworthy association grows at relatively low altitudes (roughly below 6,000 feet) on the flood plains of the major rivers. Seepwillow baccharis, Fremont cottonwood, mesquite, and arrowweed are common species forming either dense thickets or open groves (fig. 32). In much of the area fivestamen tamarisk has completely replaced the native vegetation.

Streams at elevations between 2,000 and 6,000 feet with intermittent flow constitute a second general situation. Arizona sycamore, willows, Fremont cottonwood, Arizona walnut, and boxelder are found along these streams at the higher elevations. Tamarisk is rare in this association. Below 3,000 feet elevation, desert washes of infrequent flow are occupied by mesquite, desert-willow, broom baccharis, and blue paloverde.

Figure 32. --Flood plain of the Salt River near Granite Reef Dam, Arizona. Tamarisk is growing along the river on the islands, and along the road in the background. The larger trees are mesquite and cottonwood. The lighter patches near the trees are arrowweed.

In the higher mountains above 6, 000 feet perennial streams are characteristically lined with alder, maples, willows, and other deciduous species.

METHODS OF DETERMINING WATER LOSS

Various methods have been used to estimate the amount of water lost from phreatophyte vegetation. One of the earliest methods was to determine water loss between two stream-gaging stations. Such measurements neither evaluate water loss by individual species nor separate evaporation from transpiration losses.

Another method measures directly the amount of water vapor produced by a plot. Decker and Wetzel (1957) used an adaptation of this method to show that transpiration of tamarisk seedlings increased with light intensity and temperature and decreased with absolute humidity. A mobile apparatus for use in the field was developed and is in current use (figs. 33, 34).

Measurements were made by this method during July and August 1958. The experimental area was in an old bed of the Salt River about 20 miles upstream from Tempe. The water table was 2 to 10 inches below ground surface. Evapo-transpiration rates increased linearly with the amount of tamarisk on the plot (fig. 34). They varied between about 60 and 130 grams per minute. These rates can be converted to inches per hour by multiplying by a factor of 0. 000324.

LIFE HISTORY OF PHREATOPHYTES

Studies so far have included work on seed germination, seedling establishment, sprouting ability, root development, plant succession, and effect of livestock utilization.

Figure 33. --In 1958 this apparatus was developed for measuring comparative evapo-transpiration of undisturbed naturally vegetated plots 10 feet in diameter and including shrubs up to 10 feet high. The apparatus consists of two transparent plastic tents with ventilating blowers, a sampling system, and an infrared-gas analyzer that acts as a highly sensitive hygrometer for measuring absolute humidity directly. All equipment and accessories fit into a 4-wheel-drive Willys station wagon for field operations beyond established roads.

Tents are erected over adjacent plots and are ventilated at known rates. Absolute humidity of air entering and leaving a tent is measured. Humidity difference multiplied by ventilation rate gives rate of vapor production within a tent. Evapo-transpiration rates measured with this equipment are shown in figure 34.

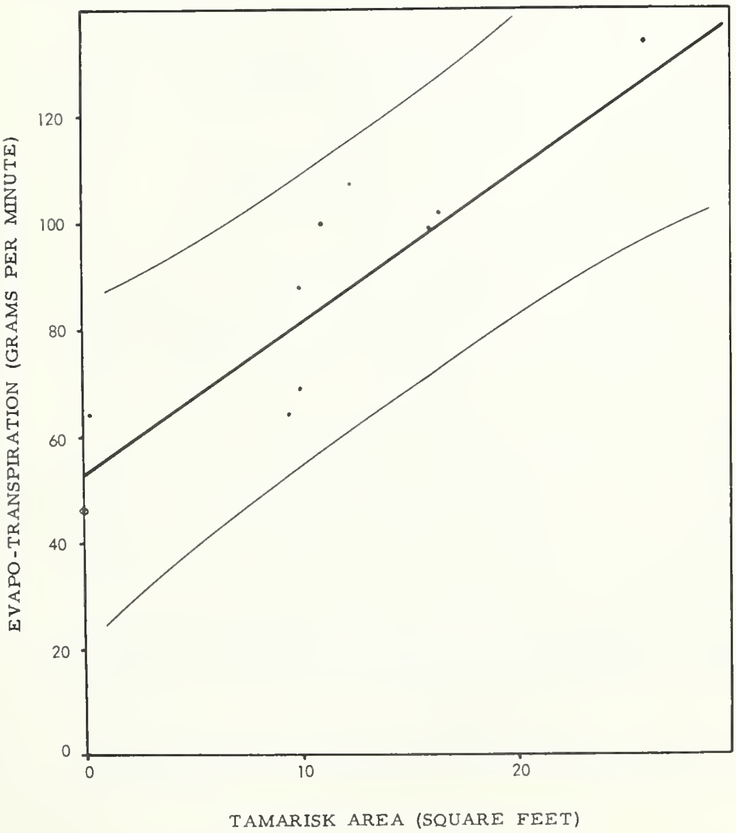


Figure 34. --Evapo-transpiration rates for different densities of tamarisk on 10-foot circular plots. Equation for the regression is 52.9 + 2.85 X, with the slope significant at the .01 level. The mean evapo-transpiration rate for 8 plots containing only Bermudagrass sod is circled on the ordinal axis to illustrate the relatively lower rate of evapo-transpiration for this type of cover compared with tamarisk.

Seed Viability

Many phreatophyte species produce numerous, small, windblown seed. On the Salt River east of Tempe, Arizona, large quantities of tamarisk seed are produced from April through September. Maximum production is reached in May and June.

Tamarisk

Fresh seed of tamarisk often shows 100 percent germination when spread on moist filter paper in closed petri dishes. Most seeds germinate within 24 hours after moistening. Seeds collected along the Salt River between April 1 and July 31, lost most of their viability in 12 weeks and by the following winter only an occasional seed would germinate. Thus, seeds produced in the spring do not carry over to germinate the following season.

Tamarisk seeds ripening in the late summer (August-September) retained some viability for nearly a year, though 70 percent of the seeds gave no germination after 12 weeks. But summer seeds may carry over and germinate in the next growing season.

Other Species

Each of the other species tested had a distinct pattern of viability with respect to storage. Seepwillow seed gave a lower initial germination than tamarisk seed, but germinating capacity was retained for a long period. Broom baccharis seeds began to show some loss of viability after a year of storage. Fremont cottonwood seed lost all viability by the seventh week after collection. Arrowweed seed maintained fairly constant but low germination for at least a year.

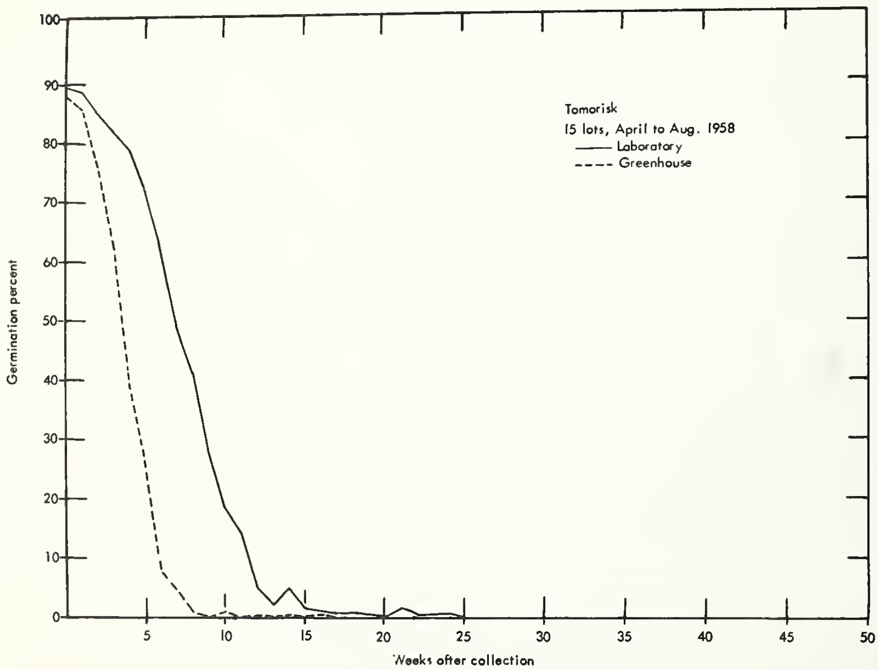


Figure 35. --Tamarisk seed stored under greenhouse temperatures of 95°F. to 105°F. loses viability more quickly than those stored in the laboratory at 72°F. to 80°F.

Effect of Storage Temperature upon Viability of Seed

High temperatures, comparable to those in the field, were found to reduce viability of tamarisk seed. Greenhouse-stored seed deteriorated about twice as fast as laboratory-stored seed (fig. 35). Contrawise, seed of both tamarisk and seepwillow retain viability for periods well over a year when stored at 40°F. (fig. 36).

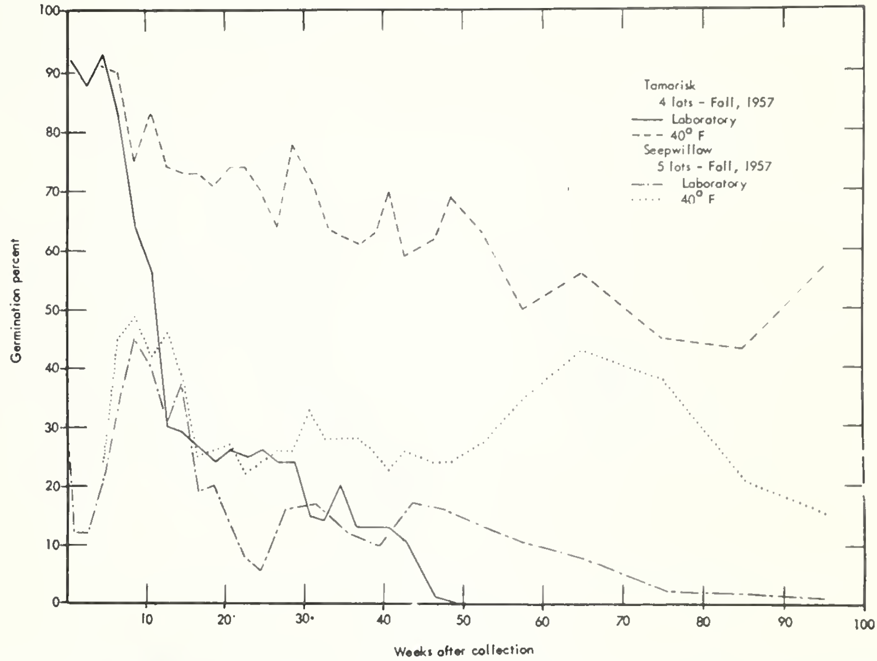


Figure 36. --Seed of tamarisk and seepwillow stored at 40°F. retained higher germination over a longer period than those stored at 72°F. to 80°F.

Effect of Moisture upon Germination of Fresh Seed

Adequate moisture is undoubtedly the principal factor inducing germination of fresh tamarisk seed. Tamarisk seed germinates while floating on water. Numerous germinating seeds were observed on the water surface of Salt River in the springs of 1957, 1958, and 1959. Moreover, early germination tests indicated that very moist conditions were needed for satisfactory germination.

Seeds sown on soil in closed petri dishes would germinate even when the soil was dry. The atmosphere inside the closed dish was probably close to 100 percent relative humidity even with comparatively dry soil. Humidity apparently supplied sufficient moisture to germinate the seed. However, in open dishes the soil had to be kept wet for any appreciable germination.

Seeds wet for 2 hours or more start their germination to such an extent that they are killed by subsequent drying. Thus, intermittent summer rains would have an adverse effect upon establishment of seedlings under natural conditions.

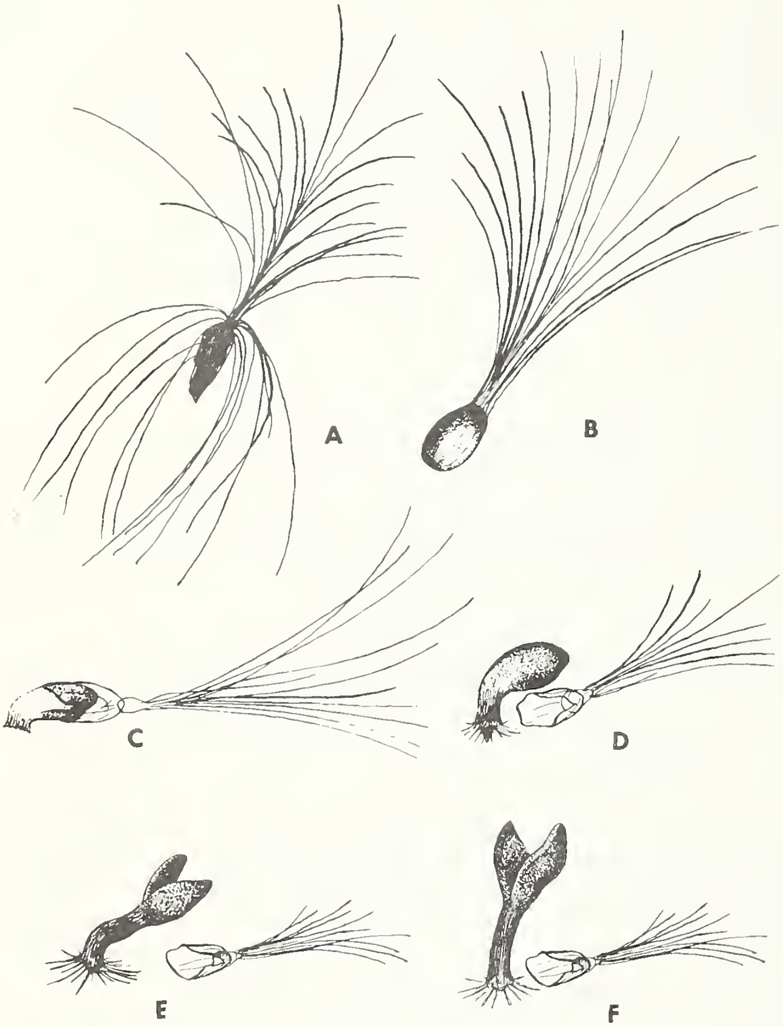
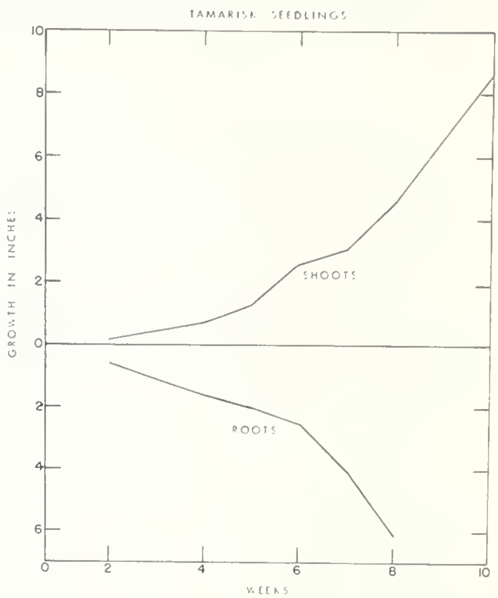


Figure 37. --Development of tamarisk seedling. A, Dry seed; B, Seed moistened several hours; C, Seedling 8 hours after moistening; D, Seedling 24 hours after moistening; E, Seedling 40 hours after moistening; F, Seedling 48 hours after moistening. In 8 hours, the embryo has usually swollen enough to break the seed coat. By 24 hours the seedling is free from the seed coat, the stem has turned downward, and a corona of root hairs has developed around the end of the root to anchor the seedling. As the stem straightens, the cotyledons separate. Drawing by Dennis Jackson.

Figure 38. --Growth of tamarisk shoots and roots grown in the greenhouse. Development is slow. At 4 weeks, seedlings grown in the greenhouse averaged less than an inch in height and roots less than 2 inches in length. In 5 or 6 weeks growth of both shoots and roots accelerates. After 8 weeks the roots had reached the bottom of the clay pot and were too intertwined to measure.

Because of slow development of the seedlings, they cannot survive except under ideal conditions. Under greenhouse conditions, seedling establishment was successful only on saturated soils at temperatures about 80°F. Seedlings did not become established on soils that were watered daily and then allowed to drain to field capacity.



Seedling Survival

Studies have been made both in the laboratory and in Salt River experimental area to determine the more important factors limiting seedling survival.

Laboratory Studies

Tamarisk seedlings are not drought resistant. Two-month-old seedlings of tamarisk grown in the laboratory will not survive more than 1 or 2 days after they wilt. Seepwillow is slightly more drought resistant than tamarisk.

Seedlings of tamarisk will survive long periods of submergence. Six weeks of complete submergence were needed to injure or kill tamarisk seedlings in the laboratory.

Seedling Establishment under Variable Flow

Under natural conditions tamarisk and seepwillow seeds germinate in wet soils or on water surfaces. Receding flood flows provide excellent conditions for seedling establishment. A side channel of the Salt River has been observed closely since January 1957. At the beginning of February 1957, the entire channel area from near high-water mark down to low water was covered with numerous tamarisk and a few seepwillow seedlings that had become established in the fall of 1956. Each subsequent high flow removed all submerged seedlings. As each of these flows receded, tamarisk and seepwillow seedlings developed in the wet soil, if seeds were available.

Apparently, seedlings of these phreatophytes can become permanently established only after high flows that not only recede during periods of abundant seed, but also are not followed by subsequent flows of equal height.

Sprouting Ability of Tamarisk

Stem cuttings of tamarisk produced vigorous roots and shoots, and formed new plants under greenhouse conditions (fig. 39). Sprouting ability was not affected by size of the cuttings; however, it did differ considerably from one season to another (fig. 40).

Root cuttings did not produce shoots and soon died for lack of photosynthetic tissue. Under field conditions, sprouts have not been observed developing from severed roots. Only crown or stem material left in the ground has formed new plants.

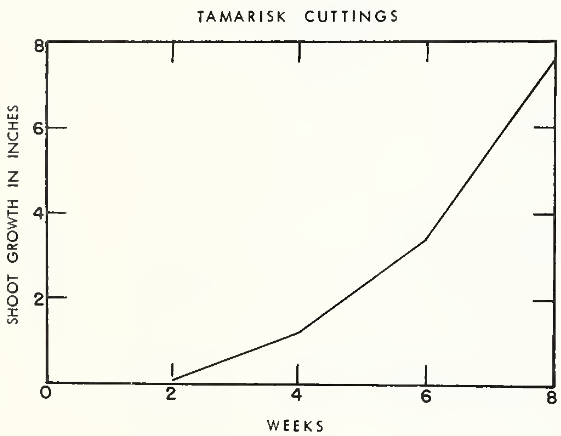


Figure 39.--Growth of shoots on tamarisk stem cuttings during an 8-week period.

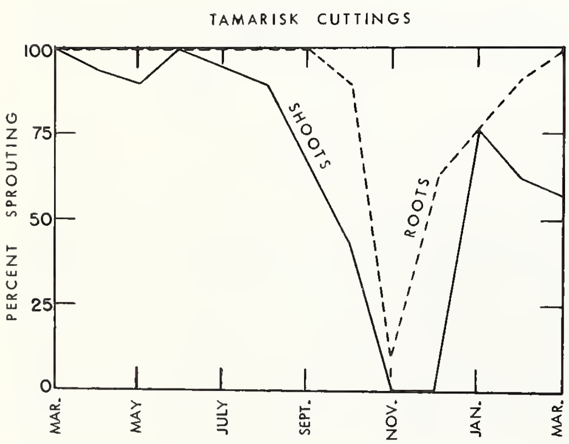


Figure 40.--Proportion of tamarisk stem cuttings that produced new root sprouts and shoot sprouts at different seasons. There were more root sprouts at all seasons; however, sprouting of both kinds was greatly reduced during the fall.

ROOT DEVELOPMENT

Entire root systems of seepwillow and arrowweed were hydraulically excavated from the alluvial banks of the Salt River in central Arizona.

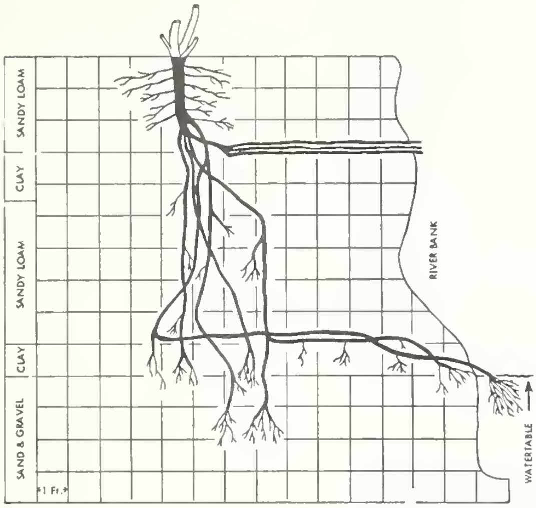


Figure 41. --Root system of large tamarisk shrub growing in deep soil, with the water table at 10 feet. Horizontal roots form on the surface of clay layers. There is a definite taproot, with most of the branch roots extending vertically to the water table.

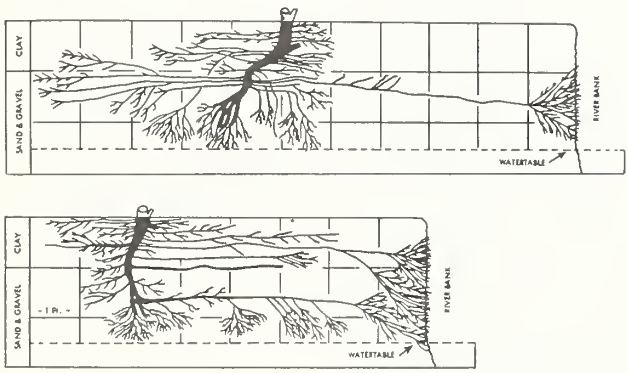


Figure 42. --Root systems of two tamarisk shrubs growing on a shallow water table. In such areas, tamarisk plants have a definite taproot but most of the branch roots extended horizontally. With both shallow and deep water-table levels, the main concentration of feeder roots was confined mostly to the area immediately above the water table. Some roots extend into the water table.

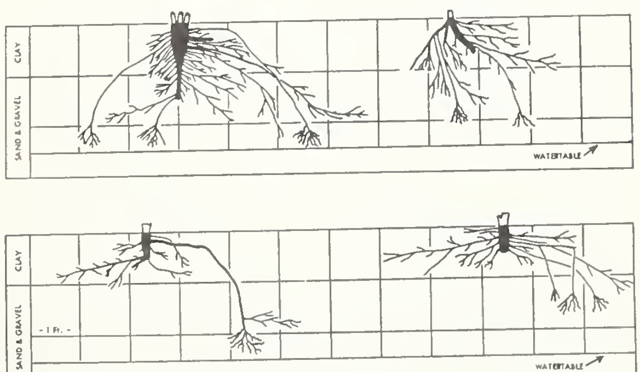


Figure 43. --Seepwillow develops a shallow taproot with an extensive feeder root system when growing over a shallow water table.

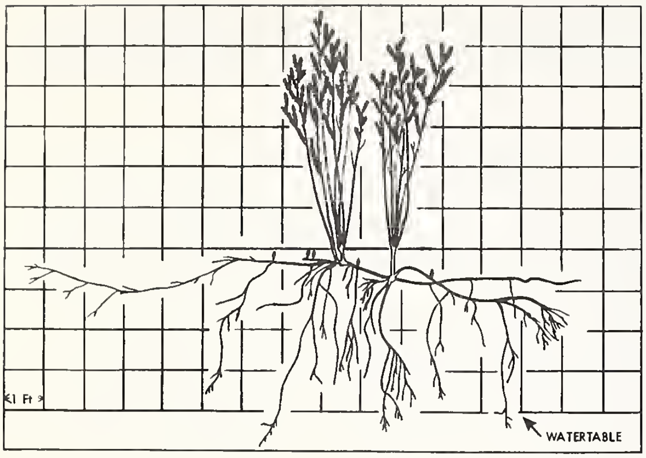


Figure 44. --Arrowweed has a lateral root system with frequent sprouts from the spreading roots. The root system is very extensive, and many plants in a thicket were found to be connected by a common lateral root development.

SUCCESSIONAL TRENDS

The most striking change in the phreatophyte areas of the Southwest is the aggressive spread of tamarisk. The species invades bare sediments of aggrading stream channels with startling rapidity until most of the flood plain areas of the major rivers have become dominated by tamarisk.

In the more stable stream channels spread is much slower. The species has been found scattered throughout the Arizona mountains below 5,000 feet. In some places, the shrubs have spread from roadside or ranch plantings; others from old erosion-control plantings. In Tonto Creek, tamarisk were used for gully control by the Civilian Conservation Corps program in the mid-thirties. These shrubs have survived and scattered groups of individuals are now established for some distance downstream.

UTILIZATION BY LIVESTOCK

Cattle browse heavily on vigorous tamarisk shoots where the shrubs are growing in open stands mixed with grass. Preliminary measurements taken in fenced and open areas along the Salt River point out that this may help suppress tamarisk (figs. 45 and 46).

CONTROL OF PHREATOPHYTES

Phreatophyte control involves removal of mature stands of shrubs and trees and establishment and maintenance of a more suitable replacement vegetation as well as suppression of seedlings invading channels after flood flows.

Several methods of control have been tried with varying degrees of success, particularly in mature stands dominated by tamarisk. Much is yet to be learned about control procedures, species to be used for replacement, and their management. Among the methods of control that have been tried are mechanical clearing

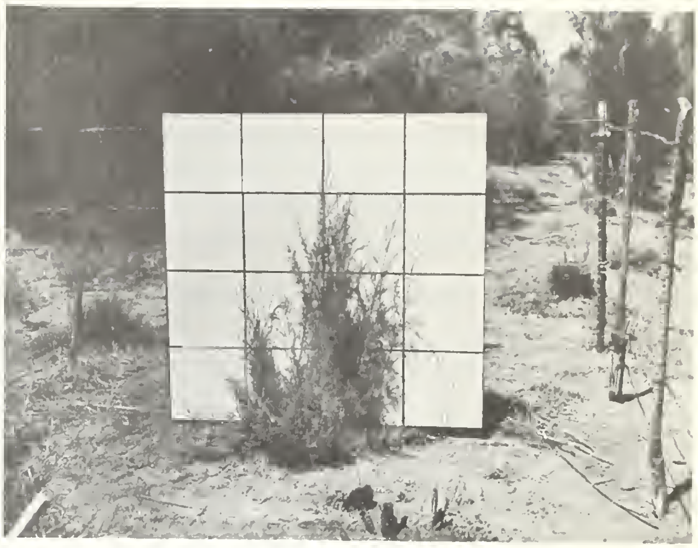


Figure 45. --Sprouts developed from the root crown of a tamarisk shrub in 5 weeks. The fence has protected the sprouts from grazing.

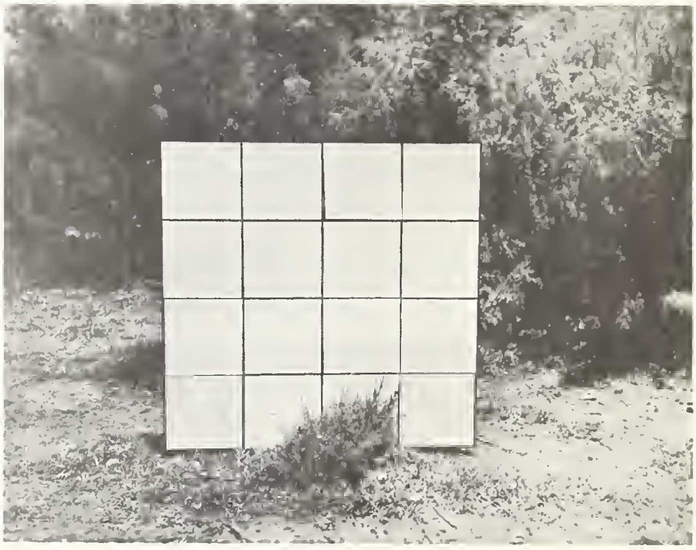


Figure 46. --Shrubs unprotected from grazing are clipped by livestock, and sprouts have reached only 1 foot in 5 weeks.

by bulldozing, root plowing, and disking; application of chemicals; and lowering of the ground-water table. The Forest Service program has not yet actively entered into this field of research but has attempted to obtain information that will apply directly to the development of more effective control measures.

Mechanical Control

To obtain effective and permanent mechanical control, the root crowns must be severed from the root system and the tops must be dried before they can take root. In a test on the Gila River near Arlington, the Fleco root plow (see fig. 22) mounted on a D-7 tractor proved to be a cheap and effective method for controlling tamarisk. The plow was pulled 12 to 18 inches below the soil surface.

If mechanical measures are successful, there will be no reinvasion of tamarisk until the area is flooded, because saturated soils are needed to establish seedlings.

In floodways, reinvasion cannot be prevented and clearing must be done following every flooding. For temporary control, disking or use of a rotary brush-cutter will keep a floodway open.

Chemical Control

Tamarisk is generally resistant to the common systemic herbicides (Arle, 1957). Three or more applications of herbicide over a period of 2 years are required to eradicate mature tamarisk. Regrowth and seedlings (6 months old or less) are more readily killed than plants a year or more old. A single application of 2 pounds per acre of 2, 4-D will kill young plants. 2-(2, 4, 5-trichlorophenoxy) propionic acid (silvex) is more effective than 2, 4-D or 2, 4, 5-T, or a mixture of the two.

At the present, the most effective method of eliminating a stand of tamarisk is to clear mechanically, to burn debris, and to treat regrowth with chemicals after several months. When regrowth is sparse, individual shrubs can be treated. Thus, the more effective the mechanical treatment, the less followup chemical treatment will be needed. Tamarisk seedlings should be sprayed with herbicides before the seedlings are 6 months old. The chemical method holds considerable promise for use in floodways where frequent invasion of tamarisk seedlings are to be expected.

Water Control

Lowering water-table levels will reduce amount of water lost both by transpiration from phreatophytes and by evaporation from soil surfaces.

Prevention of flood flows from spreading over flood plains by means of channelization and levees also avoids the possibility of establishing tamarisk seedlings. Water releases from reservoirs can sometimes be used to control tamarisk invasion of stream channels below the dam. A high flow will remove most submerged seedlings up to several months old. A rapidly receding flow does not provide suitable conditions for establishment of seedlings even while the weather is warm.

REPLACEMENT SPECIES

After the undesired phreatophytes are cleared, other species, often equally undesirable, will in time naturally invade the cleared area. Therefore, provision must be made for management of such cleared lands. In some areas cultivation and planting of crops are possible. Establishment of a sod-forming grass may create conditions unfavorable for the return of phreatophytes. Bermudagrass appears to be a suitable species for this purpose. Cattle grazing on Bermudagrass also browse on new growth of tamarisk reducing vigor of established plants.

COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

Alder	Alnus spp.
Arizona	A. oblongifolia Torr.
Algerita	Mahonia trifoliolata (Moric.) Fedde
Arrowweed	Pluchea sericea (Nutt.) Coville
Aspen, quaking	Populus tremuloides Michx.
Baccharis, broom	Baccharis sarothroides A. Gray
seepwillow	B. glutinosa Pers.
Bermudagrass	Cynodon dactylon (L.) Pers.
Bluegrass, Kentucky	Poa pratensis L.
mutton (muttongrass)	P. fendleriana (Steud.) Vasey
Boxelder	Acer spp.
Ceanothus, desert	Ceanothus greggii A. Gray
Cliffrose	Cowania mexicana D. Don
Cottonwood	Populus spp.
Fremont	P. fremontii S. Wats.
Desertwillow	Chilopsis linearis (Cav.) Sweet
Douglas-fir	Pseudotsuga menziesii (Mirb.) Franco
Fescue, Arizona	Festuca arizonica Vasey
Fir	Abies spp.
subalpine	A. lasiocarpa (Hook.) Nutt.
white	A. concolor (Gord. & Glend.) Lindl.
Juniper, alligator	Juniperus deppeana Steud.
Utah	J. osteosperma (Torr.) Little
Locust, New-Mexican	Robinia neomexicana A. Gray
Lovegrass, weeping	Eragrostis curvula (Schrad.) Nees
Manzanita	Arctostaphylos spp.
pointleaf	A. pungens H. B. K.
Pringle	A. pringlei Parry
Maple	Acer spp.
bigtooth	A. grandidentatum Nutt.
Menodora	Menodora spp.
Mesquite	Prosopis spp.
Mountainmahogany	Cercocarpus spp.
Muhly, mountain	Muhlenbergia montana (Nutt.) Hitchc.
Muttongrass (see bluegrass, mutton)	
Oak	Quercus spp.
Emory	Q. emoryi Torr.
Gambel	Q. gambelii Nutt.
shrub live	Q. turbinella Greene
Orchardgrass	Dactylis glomerata L.
Paloverde, blue	Cercidium floridum Benth.
Pine, pinyon	Pinus edulis Engelm.
ponderosa	P. ponderosa Lawson
Redtop	Agrostis alba L.

Seepwillow (see baccharis, seepwillow)	
Silktassel	Garrya spp.
Wright	G. wrightii Torr.
Spruce	Picea spp.
blue	P. pungens Engelm.
Engelmann	P. engelmannii Parry
Sumac, skunkbush	Rhus trilobata Nutt.
sugar (mountain-laurel)	R. ovata S. Wats.
Sycamore, Arizona	Platanus wrightii S. Wats.
Tamarisk, fivestamen (saltcedar)	Tamarix pentandra Pall.
Walnut, Arizona	Juglans major (Torr.) Heller
Wheatgrass, slender	Agropyron trachycaulum (Link) Malte
Willows	Salix spp.

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